Competitive Transmission Path Assessment for Local Market Power Mitigation

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Abstract-- **Market power in wholesale electricity markets is of paramount concern to energy market monitors and regulators worldwide. Transmission constraints can and often do create market power opportunities. Transmission constraints into a generation-constrained load pocket can result in limited competition for meeting demand in that region due to a high local ownership concentration of supply. In this circumstance, generation owners within the load pocket can withhold capacity and induce congestion on connecting paths, creating an uncompetitive situation for the residual demand in that location. Identifying the existence of local market power in this circumstance relies on developing a methodology that can accurately differentiate transmission constraints that are "competitive", *i.e.*, for which there is sufficient competition to avoid or relieve congestion, from those that are not. This paper provides a new methodology (called the "Feasibility Index" or "FI" method) to perform such a classification for California ISO, and compares it with methods previously used at Pennsylvania-Jersey-Maryland (PJM) and Midwest ISO (MISO).**

The term "transmission path", or simply "path", is used here to denote a transmission interface for which transmission constraints are enforced in the scheduling and market-clearing process. Pivotal supplier analysis, *i.e.*, assessing whether any single supplier is indispensable for providing congestion relief, is central to competitive path assessment. It is a common feature of competitive path assessment methodologies used in PJM and MISO, and the new methodology developed for California ISO. The approach used in PJM and MISO is to use Shift Factors (also known as Power Transfer Distribution Factors) to determine the impact of specific generation resources on the power flow on individual transmission paths. Shift factors require an arbitrary choice of a slack bus (single or distributed slack) as the sink for power injected at the location (node) in question to determine the resulting change in the flow on the path of interest. This choice has a potentially important impact on the outcome. The FI methodology developed for California ISO identifies pivotal supplies without the need to use shift factors; moreover, it is comprehensive in that it considers the interacting effect of all constraints at once. The FI methodology is being used to conduct a comprehensive competitive path assessment for the California ISO network using a detailed 3,000-node network model in preparation for implementation of the Market Design and Technology Upgrade (MRTU) project in early 2008.

Index Terms-- **Competitive path assessment, pivotal supplier analysis, local market power analysis.**

I. INTRODUCTION

THERE are several distinct types of market power opportunities that transmission constraints can present [1, 2]. The most familiar is high concentration of supply within load pockets. In that case, by withholding capacity, local generation can induce congestion on connecting paths creating an uncompetitive situation for the residual demand in that location. Another example involves the interaction of generation controlled by a single supplier in different parts of the network; in certain situations, market power can be exercised by pricing a generator at one location below marginal cost at that location in order to deliberately create congestion that raises prices for other generators at other locations. A third situation arises in generation pockets, in which generators withhold output to decongest a line, depriving the transmission rights owners of congestion revenues.

The focus of competitive path analysis described in this paper is the identification of transmission constraints that result in the first type of uncompetitive condition mentioned above, *i.e.*, high concentration in the supply-deficient areas. This is arguably the most prevalent and important type of market power caused by transmission limitations.

One common measure of market power is pivotal supplier assessment. This involves determining whether demand within a particular region can be met absent the supply of a given supplier (or suppliers). If it cannot, the supplier(s) in question is (are) considered "pivotal". Since demand cannot be met absent a pivotal supplier's supply, that supplier can set the market clearing price (*i.e.*, can exercise market power). Pivotal supplier analysis can be applied to a group of suppliers to measure the potential for collusive market power. Pivotal supplier analysis is purely a physical analysis that is based on fixed quantities of supply and demand. This approach works reasonably well in wholesale electricity markets because of the limited amount of price responsive demand. Pivotal supplier analysis is often used to assess whether congestion on particular transmission paths can be relieved competitively. It is a common feature of the competitive path assessment methods used in Pennsylvania-Jersey-Maryland (PJM) and Midwest ISO (MISO), although those ISOs have different methods of determining the relevant supply and demand for pivotal supplier analysis [3, 4]. They both use generation shift factors, but their choice of the slack bus(es) for determination

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of generation shift factors is different. In general, and specifically in both cases of MISO and PJM, the choice of the slack bus(es) for determining the shift factors is rather arbitrary and has a potentially important impact on the outcome of the pivotal supplier analysis.

The FI methodology presented here attempts to address the pivotal supplier analysis without the need for slack bus(es) designation for the determination of shift factors. In fact, the methodology proposed here does not even use shift factors. An additional advantage of the proposed method is its comprehensiveness, in that it considers the interacting effect of all constraints at once.

The methodology for competitive path assessment (whether MISO's, PJM's or the one proposed here) starts by selecting one or more representative system conditions, load levels (and load distribution), and supply resources that would normally be available (not on forced or maintenance outage) under the assumed seasonal conditions. For a given set of load, network, and supply conditions, the question is whether there are pivotal suppliers in the sense that without their collective supply participation, congestion will exist and cannot be resolved on the path in question (and thus some load would potentially be unserved in some local area). If there are such pivotal suppliers, the path in question is designated as "non-competitive". Generally, this designation is made based on seasonal or annual studies taking into account credible system conditions. However, whether or not local market power mitigation does occur in the scheduling and dispatch processes, depends on whether or not congestion relief is needed on one or more non-competitive paths under the actual system and market conditions.

The rest of this is paper is organized as follows: Section 2 provides a brief description of the competitive path assessment methodology used at MISO. Section 3 provides a brief description of the competitive path assessment methodology used at PJM. Section 4 provides a description of the proposed FI methodology for California ISO. Section 5 presents an illustrative application of the FI methodology to a small (17 node) network and Section 6 discusses future work to extend the methodology (which is currently purely physical as stated above) to incorporate price effects.

II. BRIEF SUMMARY OF COMPETITIVE PATH ASSESSMENT METHODOLOGY USED AT MISO

The MISO methodology uses Generation Shift Factors (GSFs) to determine the impact of each supply resource on congestion causation or relief on a specific transmission interface (flow gate), and performs the pivotal supplier test on that basis. The Generation Shift Factor of a specific resource with respect to a specific flowgate indicates how much the flow on the flowgate in question would change (positive or negative in the reference direction adopted for that flowgate) as a result of an incremental (1 MW) increase in supply from the designated resource. The GSFs used in MISO's analysis are estimated from a "base case" economic (least dispatch cost) solution. In simulating the power flows to determine the GSFs, MISO increases the output of the generator being evaluated and makes a corresponding reduction in output across all other generators in the case. To ensure the GSFs are not biased due to the location of other generators, all GSFs for the flowgate are then shifted such that their median is 0.

A supplier is said to be pivotal when it is able to cause a transmission (flowgate) constraint to be binding on the MISO system that cannot be resolved by redispatching other suppliers' generation. The following ratio is used to make such determination for a candidate supplier using GSFs:

$$\frac{IncFlow_{\sup plier} + DecFlow_{others} - FlowgateHeadroom}{FlowgateLimit}$$

where,

$$\boldsymbol{IncFlow_{\sup plier} = \sum_i PGSF_i * AvailCap_i - \sum_j NGSF_j * Output_j}$$

for i = 1, 2, .., n and j = 1., 2, .. , m, where n is the number of generators owned or controlled by the supplier with positive GSFs and m is the number of generators owned or controlled by the supplier with negative GSFs;

$$\boldsymbol{DecFlow_{others} = \sum_i NGSF_i * AvailCap_i - \sum_j PGSF_j * Output_j}$$

for i = 1, 2,.., k and j = 1., 2,.., h, where k is the number of generators controlled by all other suppliers with negative GSFs and h is the number of generators controlled by all other suppliers with positive GSFs;

$AvailCap_i$ = available capacity on unit i, defined as the unit's maximum capacity less the unit's Output;

$Output_i$ = output of unit i in the seasonal AFC (Available Flowgate Capability) case;

FlowGate Headroom = Flowgate Limit – Flowgate's Base Flows in the seasonal AFC case; and

Flowgate Limit = Total Transfer Capability as defined in the MISO seasonal AFC Case.

The numerator indicates the net demand for the residual transfer capability on the flowgate assuming the candidate supplier uses its supply resources (whether declared on-line or not) to maximize congestion on the flowgate (in the reference flowgate direction) while other suppliers use their on-line resources to maximize congestion relief. This is done by increasing the output of the candidate supplier's units with positive GSF to Pmax (including these off-line units in the base case), decreasing the output of the candidate supplier's units with negative GSF to 0 (i.e., they are turned off), decreasing the output of all other suppliers' units with positive GSF to Pmin and increasing the output of all other suppliers' units with negative GSF to Pmax (no turn-on or turn off units). The denominator is the total supply of the transfer capability on the flowgate. This is really a residual demand index. When the index is positive, the net effect of "inc"ing and "dec"ing is excessive flow on the flowgate. This implies the supplier is able to cause and sustain congestion on the flowgate, thus it is a pivotal supplier.

The results of the pivotal analysis using Shift Factors generally are sensitive to the choice of the sink (swing bus) for computation of the Shift Factors. The translation of GSFs so that their median is 0 is an attempt to reduce the extent of such impact on the results. However, the median may not necessarily be a good choice since it would give equal weight to large and small units (so if the analysis is done on a unit or plant basis the results may be different even if the same owner owns all the units in the same plant).

III. BRIEF SUMMARY OF COMPETITIVE PATH ASSESSMENT METHODOLOGY USED AT PJM

PJM uses the so-called "Delivered Price Test" for competitive path assessment. The methodology uses shift factors defined with respect to distributed load slack as the sinks. It starts with a list of candidate paths (interfaces) to be designated as competitive or non-competitive and an annual load duration curve. The annual load duration curve is broken up into four load quartiles. For each load quartile market simulation studies are carried out with system, supply and demand conditions relevant to that load quartile. The main outcome of this initial process is the "system price", i.e., the congestion-free and lossless component of all the LMPs throughout the network for each quartile.

For each candidate interface and each load quartile/system price and effective supply curve is constructed, where for each initial supply bid segment (bid MW, bid price pair) the shift factor, SF of the supply location with respect to the interface in question is used to define the following effective price-quantity pair:

Effective MW = (bid MW) / SF

Effective Price = (System Price – Bid Price) / SF

The effective supply curve so constructed is then partitioned into four quartiles. The effective supply in each quartile defines the supply pool of interest. Pivotal analysis is then conducted taking into account each supply quartile pool in conjunction with the load quartile used to derive the effective supply price-quantity curve. The process is carried out with different load and associated supply quartiles. Generally, however, the first supply quartile for the top load quartile is of primary interest.

PJM's pivotal analysis for each supply and load quartile requires a measure of the amount of congestion relief needed (MW overload). This is obtained from simulation studies. The amount of incremental and decremental MWs needed from non-pivotal suppliers in the relevant quartile then determines whether the path is competitive or not. For a path to be competitive it must pass this test without the need for the supply of any three jointly pivotal suppliers, and do so for all load quartiles.

The pivotal supplier test is supplemented by two other tests, namely, a market share test and a market concentration (Herfindahl-Hirschman Index, HHI) test all conducted for the supply quartile pool derived for the candidate path in question as described above. It is however, not necessary for a candidate path to pass all three tests. Passing the HHI test alone or in conjunction with market share test is not sufficient. However, if a path fails the "no three-jointly-pivotal supplier" test, it may still be considered competitive if it passes the "no two-jointly-pivotal supplier" test or even "no single-pivotal supplier" test in conjunction with below threshold market share and HHI.

IV. THE FEASIBILITY INDEX METHODOLOGY

The California ISO (CAISO) needs to identify transmission constraints that could create uncompetitive conditions in local areas for use in its local market power mitigation (LMPM) procedure under its Market Redesign and Technology Upgrade (MRTU) system to be implemented in early 2008[5]. In other words, transmission constraints must be pre-designated as "competitive" or "non-competitive" paths based on seasonal or annual studies. The LMPM procedure is an important part of MRTU implementation. The LMPM procedure is to be executed before the actual supply and demand scheduling procedure based on ISO's demand forecast and the submitted supply bids and schedules; whereby supply bidders whose output must increase to eliminate congestion on non-competitive paths are to have their bids mitigated to an estimate of their marginal cost.[1]

A. *Description of the FI Methodology*

The basic idea underlying the methodology proposed here is to take out all supply resources of a specific supplier (or more suppliers, if two or more jointly pivotal supplier analysis is desired) and determine if the remaining suppliers' resources can be scheduled to meet the entire forecast load subject to the transmission constraints, i.e., to determine if a feasible solution exists with the remaining supply. This is done for a full range of the entire system's set of loads, resources, and transmission conditions with loads treated as fixed (price-taking), excluding extreme supply-demand balance conditions that would result in generators being pivotal in the absence of transmission constraints. The later extreme scenarios could be termed "system-wide pivotal conditions."[2] In case a feasible solution does exist, the supplier(s) in question is (are) not pivotal for congestion relief on any path under the set of supply/demand/system conditions. Otherwise the supplier(s)

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[1] The procedure consists of two passes of the scheduling (or dispatch) algorithm. In the first pass, only competitive paths are enforced, and supply bids are accepted to clear the market against forecast load. In the second pass, that solution is tested by enforcing all transmission constraints – including those designated as non-competitive. The second pass, in essence, checks if the first pass's solution is still feasible; if so, no bids are mitigated. If, however, the solution from the first pass is no longer feasible, the second pass then adjusts generation to achieve feasibility based on bids and relative effectiveness in relieving congestion. Suppliers whose generation increases in the second pass relative to the first then have their bids subject to mitigation. In such cases, market bids exceeding the estimated marginal cost of the unit will be mitigated to the estimated marginal cost except that market bids will not be mitigated lower than the highest accepted market bid in the first pass as that pass was based on competitive conditions. The estimated marginal cost of a resource may be based on one of three methods: (a) incremental production cost if the resource is thermal and the incremental heat rate data is available, (b) a pre-negotiated price, or (c) the mean of the market bids from the resource that had cleared under competitive conditions in the previous 90 days.

[2] If three or more generating companies are simultaneously pivotal even when there are no transmission constraints, then this is not a case of local market power, and alternative measures to control market power are required. For those scenarios, there is no point in undertaking the FI tests, since the problem does not arise because of transmission constraints.

in question is (are) pivotal for congestion relief on the paths that cause solution infeasibility.

To identify those paths and quantify the relative degree of infeasibility each cause, we define a “feasibility index” (FI) for each transmission constraint with respect to each supplier. To define the FI measure, we modify the basic scheduling and market clearing procedures by treating all transmission constraints as soft constraints with very high penalties (an order of magnitude higher than any prevailing bid cap) for violating the constraint. Additionally, in order to avoid firm load from being curtailed instead of transmission constraint violations, firm load is modeled as a vertical demand curve, *i.e.*, with extremely high demand bids that are much higher than the penalty bids on transmission constraints. Thus, instead of getting no solution or a solution caused by curtailing firm load, we would get a “least cost” solution in which one or more transmission flows exceed their transmission limits.

For a single supplier i whose resources are removed, we define the Feasibility Index (FI(i,j)) of Path j with respect to Supplier i as follows. Let:

Limit(j) = Transmission Limit on Path j

Flow(i,j) = Power Flow on Path j without Supplier i’s Resources (with soft limits)

Then:

FI(i,j) = [Limit(j) - Flow(i,j)] / Limit(j)

If FI(i,j) is negative, supplier i is pivotal for congestion relief on the system, in particular on Path j. This could be interpreted as implying that Path j is not competitive.[3] If FI(i,j) is positive, supplier i is not pivotal for congestion relief on Path j, but if FI(i,j) is small, it is possible that supplier j could be jointly pivotal with another supplier k with small feasibility index FI(k,j) on the same path j. This provides an easy means to select candidate suppliers for two or more jointly pivotal suppliers test if no single supplier is pivotal on Path j.

The following generic matrix demonstrates the single pivotal supplier test results for n candidate paths.

Paths j Suppliers i	⇨ P1 ⇩	P2	…..	Pj	….	Pn
S1	FI(1,1)	FI(1,2)				FI(1,n)
S2	FI(2,1)	FI(2,2)				FI(2,n)
.						.
Si				FI(i,j)		FI(i,n)
.				.		.

If a FI(i,j) entry is negative for any Supplier i, then Path j is non-competitive. The corresponding path will then be dropped and will no longer be a candidate as a competitive path. If all FI(i,j) entries are non-negative for Path j, but some are small (below a designated threshold), then the test is repeated with the supply resources of two suppliers removed. Only the paths with non-negative FI will be retained as competitive based on “no-two-jointly-pivotal-supplier” criterion.

For “no-three-jointly-pivotal-supplier” analysis, the analysis will continue using three supplier combinations with small non-negative FI entries.

B. Property of the FI Methodology

A full range of load, generation, and transmission system conditions are considered in the FI procedure, excluding system-wide pivotal situations. Accordingly, the set of paths that are designated as competitive by the above procedure have the following property:

> *If just the set of competitive paths are imposed as hard constraints no set of three or fewer generation companies would face a vertical residual demand curve (that is, would be pivotal) under any load, generation, and transmission outage scenario that is not a system-wide pivotal situation.*

This is true by definition of the procedure by which competitive paths are designated. Pre-designation of such paths as competitive would allow the LMPM procedure to focus on paths that could, under some circumstances, would cause residual demand curves to be vertical for some generators (or combination of two or three generating companies).

V. ILLUSTRATIVE EXAMPLE

The example provided here illustrates the calculation of the Flexibility Index to evaluate competitive and non-competitive paths using a prototype 17-node model shown in Fig. 1. The relevant data are presented in the Appendix. There are eight merchant suppliers, S1 through S8. The remaining suppliers are either utility distribution companies (UDCs) or competitive fringe suppliers (including imports), whose supply resources are assumed to be scheduled or bid competitively. Only Suppliers S1 through S8 are tested for pivotal supplier determination.[4]

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[3] However, the more correct interpretation is that the set of constraints considered is, taken together, uncompetitive. Thus, if a subset of this set excluding a given candidate path is known to be competitive, then the candidate path is deemed to be the culprit and designated as non-competitive.

[4] The engine used to perform the computations is PLEXOS for Power Systems, which is a Windows-based electricity market simulation tool (www.draytonanalytics.com/plexos_home.asp).

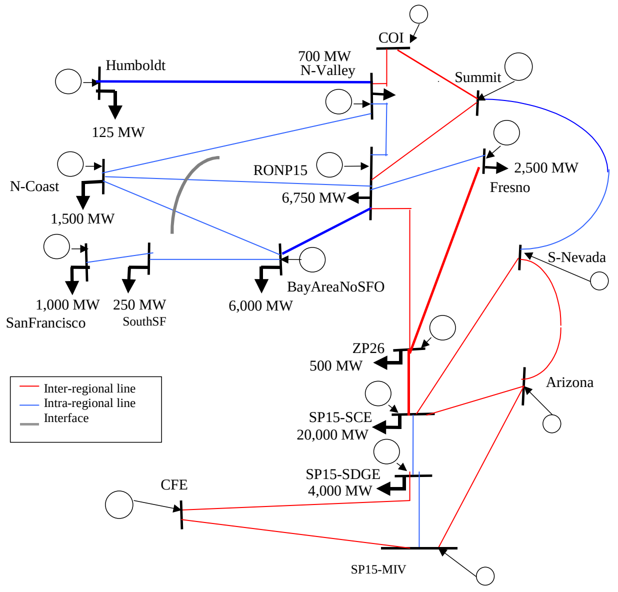

Fig. 1. 17-Node Model Used in Example

The above network topology depicts a highly simplified version of the California ISO transmission system and connections with neighboring control areas. However, this network topology is for illustration purposes[5] and the data used in this illustrative example (including the network, load and supply data) are hypothetical. Moreover, the analysis illustrates only one way the FI methodology could be used, without attempting to examine variants of the FI method that may be used in actual competitive path assessment.

The FI test was conducted for a base case and a variant. A penalty price of $3,000/MWh was used for all transmission lines and interfaces. The bid cap was $500/MWh for economic bids. A loss of load penalty of $10,000/MWh was used to ensure that transmission constraints are violated before any load is curtailed.

First, we look at the FI results with a single supplier removed. Keeping penalty prices imposed on all transmission lines and interfaces, we ran the model with each individual merchant supplier's generation capacity taken out, and then calculated the Feasibility Indices. Table 1 below shows the results for all lines in the example model for each of the eight merchant suppliers considered. Since the number of paths is larger than the number of suppliers, for ease of reference the table is transposed, showing the paths in rows and the suppliers in columns.

Table 1. Feasibility Index Results with One Supplier Removed

Line/Interface	Max Flow (MW)	Min Flow (MW)	FI w/o S1	FI w/o S2	FI w/o S3	FI w/o S4	FI w/o S5	FI w/o S6	FI w/o S7	FI w/o S8
AZ-SP15MIV	2500	-2500	81%	77%	80%	77%	85%	87%	75%	87%
AZ-SP15SCE	2500	-2500	63%	66%	65%	66%	62%	60%	67%	60%
BayArea-Ncoast	100	-100	12%	12%	12%	12%	10%	12%	12%	12%
BayArea-SouthSF	1000	-1000	14%	14%	14%	14%	-2%	14%	14%	14%
CFE-SP15SDGE	400	-400	60%	62%	60%	57%	64%	65%	65%	65%
COI-Nvalley	4800	-4800	37%	58%	57%	58%	42%	58%	58%	58%
COI-Summit	300	-300	34%	47%	67%	47%	60%	48%	47%	48%
Fresno-RONP15	1200	-1200	91%	53%	91%	53%	95%	53%	53%	53%
Fresno-ZP26	100	-100	0%	0%	0%	0%	0%	0%	0%	0%
NorthCentral	1100	-1100	51%	48%	51%	48%	52%	48%	48%	48%
NValley-Humboldt	70	-70	0%	0%	0%	0%	0%	0%	0%	0%
NValley-Ncoast	100	-100	13%	44%	44%	44%	34%	44%	44%	44%
RONP15-BayArea	6000	-6000	-2%	1%	1%	1%	0%	1%	1%	1%
RONP15-Ncoast	1000	-1000	-14%	34%	38%	34%	38%	34%	34%	34%
RONP15-Nvalley	7300	-7300	55%	56%	55%	56%	45%	56%	56%	56%
SNevada-Arizona	5000	-5000	94%	94%	95%	94%	96%	96%	93%	96%
SNevada-SP15SCE	3500	-3500	57%	59%	60%	59%	58%	56%	60%	56%
SouthSF-SanFrancisco	850	-850	28%	28%	28%	28%	9%	28%	28%	28%
SP15MIV-CFE	2500	-2500	99%	99%	99%	100%	99%	98%	98%	98%
SP15MIV-SP15SDGE	2500	-2500	61%	63%	61%	58%	65%	67%	67%	67%
SP15SCE-ZP26	3000	-4000	11%	0%	11%	0%	14%	0%	0%	0%
SP15SDGE-SP15SCE	2500	-2500	76%	74%	76%	68%	88%	94%	76%	94%
Summit-RONP15	120	-120	36%	68%	46%	69%	28%	67%	69%	67%
Summit-Snevada	300	-300	33%	41%	70%	41%	70%	44%	41%	44%
ZP26-RONP15	5300	-9999	84%	88%	79%	88%	75%	88%	88%	88%

This set of simulation results indicates that only two paths have a negative FI with respect to a single supplier, which indicates an insufficient supply of counter-flow on these two paths if that supplier withdraws all its capacity. The upshot is that, again for only one potentially pivotal suppler, the paths RONP15-BayArea and BayArea-SouthSF would be declared "non-competitive" for purposes of applying market power mitigation.

Now we move to calculating the FI based on two-jointly-pivotal suppliers. For simplicity, not all combinations of two jointly pivotal suppliers were tested. Moreover, for ease of comparison, we did not exclude the paths with negative single-pivotal-supplier FI from two-jointly-pivotal suppliers test. Accordingly, we included suppliers whose single supplier FI values were negative, zero, or small positive numbers. The following table summarizes the FI values with the capacity of two suppliers removed simultaneously.

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[5] At present, as well as under the initial implementation of MRTU, interconnections with external control areas are modeled as radial paths (rather than looped as shown in Figure 1).

Table 2. Feasibility Index Results with Two Suppliers Removed Simultaneously

Line/Interface	Max Flow (MW)	Min Flow (MW)	FI w/o S1 & S5	FI w/o S2 & S4	FI w/o S5 & S6	FI w/o S4 & S6	FI w/o S4 & S5	FI w/o S1 & S6
AZ-SP15MIV	2500	-2500	87%	73%	87%	77%	77%	87%
AZ-SP15SCE	2500	-2500	83%	68%	61%	65%	66%	60%
BayArea-NCoast	100	-100	14%	12%	10%	12%	10%	17%
BayArea-SouthSF	1000	-1000	-2%	14%	-2%	14%	-2%	14%
CFE-SP15SDGE	400	-400	68%	59%	66%	58%	57%	65%
COI-NValley	4800	-4800	35%	58%	42%	58%	41%	37%
COI-Summit	300	-300	73%	46%	53%	47%	51%	32%
Fresno-RONP15	1200	-1200	87%	53%	95%	53%	95%	68%
Fresno-ZP26	100	-100	-105%	0%	0%	0%	0%	0%
NorthCentral	1100	-1100	4%	48%	52%	48%	52%	4%
Nvalley-Humboldt	70	-70	0%	0%	0%	0%	0%	0%
Nvalley-Ncoast	100	-100	10%	44%	33%	44%	33%	13%
RONP15-BayArea	6000	-6000	-5%	1%	0%	1%	0%	-2%
RONP15-Ncoast	1000	-1000	-14%	34%	38%	34%	38%	-14%
RONP15-Nvalley	7300	-7300	31%	56%	45%	56%	45%	33%
SNevada-Arizona	5000	-5000	92%	93%	96%	94%	94%	96%
SNevada-SP15SCE	3500	-3500	91%	60%	57%	59%	60%	55%
SouthSF-SanFrancisco	850	-850	9%	28%	9%	28%	9%	28%
SP15MIV-CFE	2500	-2500	98%	99%	98%	100%	100%	98%
SP15MIV-SP15SDGE	2500	-2500	70%	60%	67%	58%	58%	67%
SP15SCE-ZP26	3000	-4000	13%	0%	0%	0%	0%	0%
SP15SDGE-SP15SCE	2500	-2500	74%	65%	94%	70%	68%	94%
Summit-RONP15	120	-120	-7%	69%	34%	68%	36%	38%
Summit-SNevada	300	-300	84%	41%	62%	41%	59%	30%
ZP26-RONP15	5300	-9999	48%	88%	75%	88%	75%	84%

With two suppliers being taken out, more transmission lines/interfaces show up with negative FI values and are therefore labeled as non-competitive. In addition to BayArea-SouthSF and RONP15-BayArea the following lines have negative FI values and would be deemed "non-competitive": Fresno-ZP26, RONP15-Ncoast, Summit-RONP15.

The last set of results represents the FI values when three suppliers are removed simultaneously (Table 3). Again for simplicity, not all combinations of three jointly pivotal suppliers were tested. We considered suppliers whose single supplier FI values and the two-supplier FI values were negative, zero, or small positive numbers.

Table 3. Feasibility Index Results with Three Suppliers Removed Simultaneously

Line/Interface	Max Flow (MW)	Min Flow (MW)	FI w/o S1 & S5 & S6	FI w/o S2 & S4 & S6	FI w/o S5 & S6 & S8
AZ-SP15MIV	2500	-2500	95%	95%	95%
AZ-SP15SCE	2500	-2500	79%	79%	79%
BayArea-Ncoast	100	-100	14%	10%	6%
BayArea-SouthSF	1000	-1000	-2%	-2%	-2%
CFE-SP15SDGE	400	-400	71%	71%	71%
COI-Nvalley	4800	-4800	35%	35%	35%
COI-Summit	300	-300	74%	74%	74%
Fresno-RONP15	1200	-1200	87%	113%	87%
Fresno-ZP26	100	-100	-104%	-104%	-104%
NorthCentral	1100	-1100	4%	4%	4%
Nvalley-Humboldt	70	-70	0%	0%	0%
NValley-Ncoast	100	-100	10%	10%	10%
RONP15-BayArea	6000	-6000	-5%	-9%	-13%
RONP15-Ncoast	1000	-1000	-14%	-14%	-14%
RONP15-Nvalley	7300	-7300	31%	31%	31%
SNevada-Arizona	5000	-5000	91%	109%	109%
SNevada-SP15SCE	3500	-3500	88%	88%	88%
SouthSF-SanFrancisco	850	-850	9%	9%	9%
SP15MIV-CFE	2500	-2500	97%	97%	97%
SP15MIV-SP15SDGE	2500	-2500	74%	74%	74%
SP15SCE-ZP26	3000	-4000	13%	13%	13%
SP15SDGE-SP15SCE	2500	-2500	90%	90%	90%
Summit-RONP15	120	-120	-8%	-8%	-8%
Summit-Snevada	300	-300	82%	118%	118%
ZP26-RONP15	5300	-9999	48%	48%	48%

With three suppliers being taken out, even more negative FI values show up. The results above show that among all of the paths considered, five are non-competitive with respect to the no-three-jointly-pivotal supplier test. Of course, some other paths could also turn out to be non-competitive with other cases involving different load, supply, and system conditions. The above example illustrates only one case. An entire set of representative cases (different load levels and load distribution factors, seasonal supply outages or derates, and seasonal transmission outages or derates) would have to be examined following the same procedure to filter out other non-competitive paths and determine the set of competitive paths.

VI. FUTURE WORK – INCORPORATING EFFECTIVE COST IMPACT

The FI method as stated above employs a pivotal supplier assessment that measures whether demand can still be served absent certain suppliers' supply. As such, it is a physical measure of market power. This approach may not capture situations where a supplier is not "pivotal" but can nonetheless raise prices significantly by withholding economic generation from the market. We conjecture that a more stringent no-three pivotal supplier test may cover many or most such situations since if no subset of three suppliers are jointly pivotal, it may be difficult for any one or two of them to effectively raise market prices by withholding generation. However, with the no-two-jointly-pivotal-suppliers criterion, based on the FI alone a path may be declared competitive even if one or two suppliers, while not being indispensable for congestion relief, can raise the prices substantially by physical or economic withholding. If a no-two-jointly-pivotal-suppliers analysis is desired, a supplementary screen whereby the path or paths that pass the FI test screen are subjected to a "price movement" screen may be appropriate and could be considered.

This could be done by enforcing hard constraints on the paths that are competitive based on the FI screen mentioned above (referred to below as candidate set). Since these have passed the FI screen, a feasible solution does exist. To avoid infeasibility resulting from constraints on other paths we can adopt one of the following two approaches:

(1) Treat the remaining paths with soft constraints with high penalties as in the basic FI methodology, or

(2) Allow dummy injections (*e.g.*, at the prevailing bid cap of say, $500/MWh) at each load node.

Regardless of whether (1) or (2) is adopted, the exercise of removing one and two suppliers at a time is repeated and the movement of the nodal prices or transmission constraint shadow prices is quantified as a result. If the movement exceeds a pre-designated threshold (the lower of $x/MWh or y%, for instance), the candidate set is declared non-competitive despite having passed the no-two-pivotal-supplier FI screen. Some possible metrics and thresholds based on shadow prices of paths could include the following:

(1) Increase in the shadow price of the path in question.

Thresholds: x = $50/MWh; y = 200%

(2) Maximum increase in shadow price of any of the paths in the candidate set.

Thresholds: x = $50/MWh; y = 200%

(3) Average increase in shadow price of the paths in the candidate set.

Thresholds: x = $10/MWh; y = 50%

(4) Root Mean Square of the increase in shadow price of the paths in the candidate set.

Thresholds: x = $10/MWh; y = 50%

In each case for the path or the set that has already passed the FI test screen to pass the price movement screen, the specified threshold must not be exceeded by the shadow prices when any two-supplier portfolios are removed, compared to those with all suppliers in.

The selection of a particular screening metric and threshold requires more investigation. It will be helpful to consider the relationship between the shadow price effects and the effective demand curve facing generation in the load pocket. A large increase in the shadow price is equivalent to a large shift upwards in some effective demand curve at some location, which allows generation there to greatly increase the LMP there.

VII. APPENDIX

Data Used in the Illustrative Example

Table A-1. Network Node and Load Data

Region	Bus	Voltage	Load participation Factor	Load at Bus (MW)
Arizona	Arizona	500kV	1	0
Mexico	CFE	500kV	1	0
NorthWest	COI	500kV	1	0
NP15	BayArea-NoSFO	500kV	0.318725	6000
	Fresno	500kV	0.132802	2500
	Humboldt	500kV	0.00664	125
	N-Coast	500kV	0.079681	1500
	N-Valley	500kV	0.037185	700
	RONP15	500kV	0.358566	6750
	SanFrancisco	500kV	0.053121	1000
	SouthSF	500kV	0.01328	250
S-Nevada	S-Nevada	500kV	0.5	0
	Summit	500kV	0.5	0
SP15	SP15-MIV	500 kV	0	0
	SP15-SCE	500 kV	0.83333	20000
	SP15-SDGE	500 kV	0.16667	4000
ZP26	ZP26	500 kV	1	500

Table A-2. Transmission Capacities

Line	Max Flow (MW)	Min Flow (MW)	From Region	To Region	Category
AZ-SP15MIV	2500	-2500	Arizona	SP15	Inter-regional
AZ-SP15SCE	2500	-2500	Arizona	SP15	Inter-regional
CFE-SP15SDGE	100	-100	Mexico	SP15	Inter-regional
COI-NValley	1000	-1000	NorthWest	NP15	Inter-regional
COI-Summit	400	-400	NorthWest	S-Nevada	Inter-regional
Fresno-ZP26	4800	-4800	NP15	ZP26	Inter-regional
SNevada-Arizona	300	-300	S-Nevada	Arizona	Inter-regional
SNevada-SP15SCE	1200	-1200	S-Nevada	SP15	Inter-regional
SP15MIV-CFE	100	-100	SP15	Mexico	Inter-regional
SP15SCE-ZP26	70	-70	SP15	ZP26	Inter-regional
Summit-RONP15	100	-100	S-Nevada	NP15	Inter-regional
ZP26-RONP15	6000	-6000	ZP26	NP15	Inter-regional
BayArea-NCoast	1000	-1000	NP15	NP15	Intra-regional
BayArea-SouthSF	7300	-7300	NP15	NP15	Intra-regional
Fresno-RONP15	5000	-5000	NP15	NP15	Intra-regional
NValley-Humboldt	3500	-3500	NP15	NP15	Intra-regional
NValley-NCoast	850	-850	NP15	NP15	Intra-regional
RONP15-BayArea	2500	-2500	NP15	NP15	Intra-regional
RONP15-NCoast	2500	-2500	NP15	NP15	Intra-regional
RONP15-NValley	3000	-4000	NP15	NP15	Intra-regional
SouthSF-SanFrancisco	2500	-2500	NP15	NP15	Intra-regional
SP15MIV-SP15SDGE	120	-120	SP15	SP15	Intra-regional
SP15SDGE-SP15SCE	300	-300	SP15	SP15	Intra-regional
Summit-SNevada	5300	-9999	S-Nevada	S-Nevada	Intra-regional

Table A-3. Supply and Ownership

Region	Bus	Generator	Capacity (MW)	Owner
Arizona	Arizona	OTH_ARIZ_T	2500	OTH
Mexico	CFE	OTH_CFE_T	400	OTH
NorthWest	COI	OTH_COI_T	4800	OTH
S-Nevada	BayArea-NoSFO	S1_BAREA_T	476.1	S1
		OTH_BAREA_H	9.5	OTH
		OTH_BAREA_T	133.1	OTH
		UDC1_BAREA_H	280	UDC1
		UDC1_BAREA_T	225.6	UDC1
	Fresno	OTH_Fresno_T	259.4	OTH
		UDC1_FRESNO_H	1878.5	UDC1
		UDC1_FRESNO_T	317.6	UDC1
	Humboldt	OTH_HUMBOLDT_T	48	OTH
		UDC1_HBOLDT_H	1015	UDC1
		UDC1_HUMBOLDT_T	182.4	UDC1
	N-Coast	S1_NCOAST_T	793	S1
		UDC1_NCOAST_H	215	UDC1
		UDC1_NCOAST_T	144.6	UDC1
	N-Valley	OTH_NVALLEY_H	6.4	OTH
		OTH_NVALLEY_T	44	OTH
		UDC1_NVLLEY_H	2142.1	UDC1
		UDC1_NVLLEY_T	412.4	UDC1
	RONP15	S1_NP15_T	2340.1	S1
		S3_NP15_T	2687.7	S3
		S5_NP15_T	2580	S5
		OTH_NP15_H	5.4	OTH
		OTH_NP15_T	929.5	OTH
		UDC1_NP15_H	11.5	UDC1
		UDC1_NP15_T	3663.9	UDC2
		UDC2_NP15_T	2.7	UDC2
	SanFrancisco	S5_SFO_T	362	S5
		UDC1_SFO_T	230.6	UDC1
	S-Nevada	OTH_SNEV_T	3500	OTH
	Summit	OTH_SUMMIT_T	120	OTH0
SP15	SP15-MIV	S2_SP15MIV_T	330	S2
	SP15-MIV	S7_SP15MIV_T	600	S7
	SP15-SCE	S4_SP15_UDC2_T	1229.9	S4
	SP15-SCE	OTH_SP15_UDC2_H	1838.2	OTH
	SP15-SCE	OTH_SP15_UDC2_T	2317.3	OTH
	SP15-SCE	UDC1_SP15_UDC2_H	1772.3	UDC1
	SP15-SCE	S6_UDC2_T	3501.7	S6
	SP15-SCE	UDC2_SP15_UDC2_H	1580	UDC2
	SP15-SCE	UDC2_SP15_UDC2_T	7912.5	UDC2
	SP15-SCE	S8_SP15_UDC2_T	3863.1	S8
	SP15-SDGE	S3_UDC3_T	707.6	S3
	SP15-SDGE	S4_UDC3_T	1197.1	S4
	SP15-SDGE	OTH_UDC3_T	1251.5	OTH
	SP15-SDGE	UDC2_UDC3_T	1108.7	UDC2
	SP15-SDGE	UDC3_UDC3_T	336.5	UDC3
ZP26	ZP26	S3_ZP26_T	999	S3
	ZP26	OTH_ZP26_T	2465.6	OTH
	ZP26	UDC1_ZP26_H	84.5	UDC1
	ZP26	UDC1_ZP26_T	3406.9	UDC1

* Note: OTH owners are non-UDC, non-pivotal merchant suppliers

In addition to the transmission lines listed above, there is one interface consisting of two transmission lines as shown in the following Table.

Table A-4. Transmission Capacities (interface)

Interface	Line Components	Individual Line Capacity	Interface Capacity
NorthCentral	BayArea-Ncoast	1000 MW (both ways)	1100 MW (both ways)
	RONP15-Ncoast	2500 MW (both ways)	

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IX. BIOGRAPHIES

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