California Independent
System Operator Corporation

Implementation of "Partial Loop" Intertie Network Configuration for MRTU

Summary:

Plans for initial MRTU implementation have included use of an "open loop" network model that excludes transmission branches external to the CAISO. In reality, however, there are limited external loops in certain areas of the grid which, if ignored, can result in less accurate modeling of network flows, leading to adverse impacts on congestion management and distorted Locational Marginal Prices (LMPs). Recent LMP Study results have demonstrated such impacts at Palo Verde, for example. As a result, the CAISO has included additional transmission lines outside the CAISO Control Area to mitigate these impacts, specifically by adding four 500 kV lines to the network model, from Palo Verde to Westwing and Moenkopi. This modification results in what can be considered a "partial loop" model. Ultimately, the CAISO will continue to identify ways to improve its modeling of flows at its borders with other Balancing Authority Areas. However, data reviewed in this paper confirm that this needs to be done with caution in order to avoid adverse impacts on the CAISO's congestion management if the CAISO's market network model were expanded before energy schedules in other Balancing Authority Areas are made available and can be modeled.

Issue:

The CAISO's ultimate goal is to use a "closed loop" network model for purposes of managing and pricing congestion on the CAISO Controlled grid. However, at present, a lack of Day-Ahead information about conditions in other Balancing Authority Areas is an obstacle to using a closed loop model for MRTU's initial implementation, thus requiring general use of an "open loop" model. Use of the open loop model was originally explained in the July 21, 2003, "Amended Comprehensive Market Design Proposal" for MRTU:

> 2.2.4 The Full Network Model
>
> The ISO proposes eventually to utilize, in the forward markets and in Real Time, a full network model (FNM) that accurately represents constraints and interfaces of the ISO controlled grid and incorporates a model of the WECC regional grid external to the ISO control area. The external model will be a "closed-loop" model that represents external electrical connections between the various inter-ties into the ISO control area, and thus allows the ISO to explicitly estimate and manage parallel path or "loop" flows in coordination with other control areas in the region. Most significantly, the closed-loop FNM will accurately model loop flows due to internal resources and will result in accurate scheduling and dispatch of these resources to address congestion within the ISO-controlled grid.
>
> Implementation of a FNM that incorporates a "closed loop" approach is dependent on the availability and use of modeling data and forward energy schedules throughout the western

interconnected region. The ISO will be prepared to implement this approach. However, explicit forward scheduling in a manner that accounts for loop flows may create severe problems if the ISO were to adopt this feature ahead of its neighbors throughout the west. Therefore, when Phase 3 is first implemented, the ISO may need to use a simpler "open loop" representation of the external network, until such time as there is an effective, coordinated western regional framework for Day Ahead scheduling and congestion management, including explicit scheduling of inter-control area parallel path flows.

As previously released to and discussed with stakeholders, over the last several years the CAISO has conducted a number of Locational Marginal Pricing (LMP) Studies. The purpose of these studies is to provide the CAISO and stakeholders with information so that they can understand and anticipate how MRTU will impact market operations in California. The LMP Studies use historical bids to dispatch all resources in the CAISO Balancing Authority Area. LMP Study 3A, which began before the Amended Comprehensive Market Design Proposal's development was complete, used a closed-loop model. Given the conclusion of the Amended Comprehensive Market Design Proposal that an open loop model would be required initially, LMP Studies 3B and 3C subsequently used an open loop model. Three important exceptions to use of an open-loop model include: (1) intertie branch groups that consist of multiple branches to Scheduling Points that have connections among the external Scheduling Points,[1] (2) the "New PTO" network of Converted Rights that includes loops to fully represent the extent of CAISO Controlled Grid,[2] and (3) the Sacramento Municipal Utility District (SMUD) and Turlock Irrigation District (TID) Control Areas, which are modeled in detail as Integrated Balancing Authority Areas (IBAAs).[3] Each of these exceptions to the open-loop rule were included in the CAISO's Congestion Revenue Rights (CRR) model and will be included in the upcoming MRTU Update 2 market simulation.

Figures 1 and 2 demonstrate the concern that has led the CAISO to examine the type of external network model that can be feasibly implemented at the outset of the MRTU market. Both Figures 1 and 2 show the unscheduled flow at the California-Oregon border,[4] averaged using hourly intervals over periods of time, with Figure 1 showing the summer season of 2006 (May to September) and Figure 2 showing detail for the first complete week of August 2006. Figure 1 shows that the pattern of unscheduled flow over time is highly variable, reaching 600 to 800 MW in several hours. The shorter period shown in Figure 2 indicates that there is no consistency in the amount of unscheduled flow by time of day.

1 The term "branch group" refers to branch groups that are used in the CAISO's original zonal market design. The term "Transmission Interface" has now been adopted for use in the MRTU market design.

2 The modeling of the "New PTO" rights is documented at http://www.caiso.com/185d/185db75028b00.pdf

3 The CAISO now uses the term IBAA for conformance with NERC's terminology, rather than its previous terms Embedded Control Area and Adjacent Control Area. Modeling of IBAAs is described at http://www.caiso.com/1cb4/1cb4e0984a670.pdf and http://www.caiso.com/1cb4/1cb4e1a154060.pdf

4 Figures 1 and 2 show total unscheduled flow, not limited to the Malin – Round Mountain lines.

Figure 1: Unscheduled Flow at Malin (South to North)

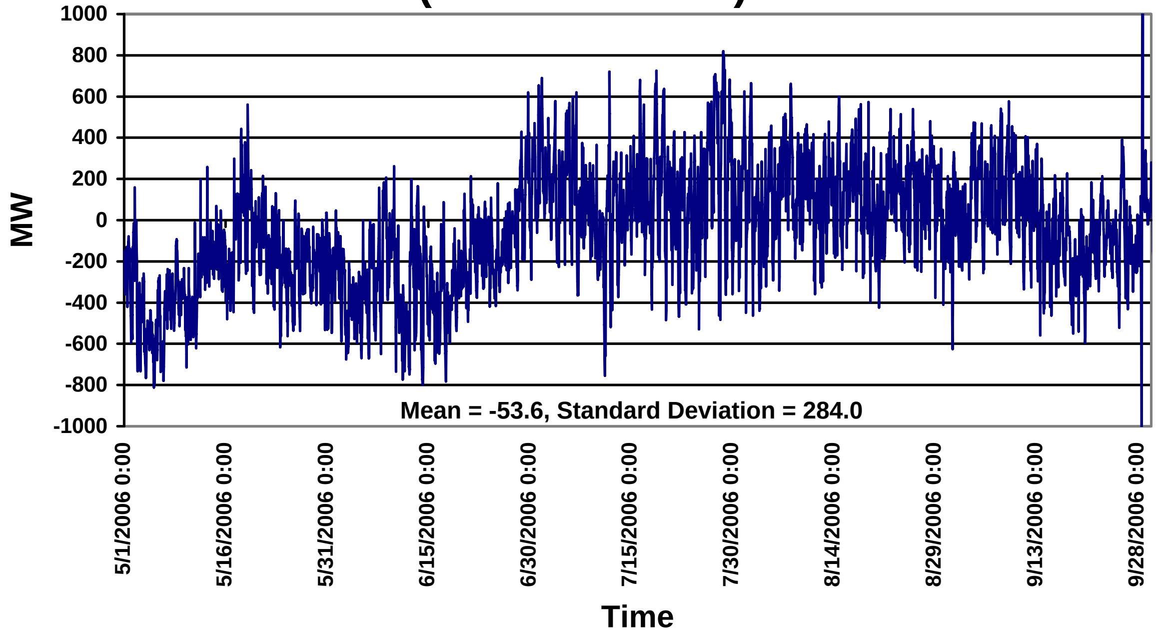
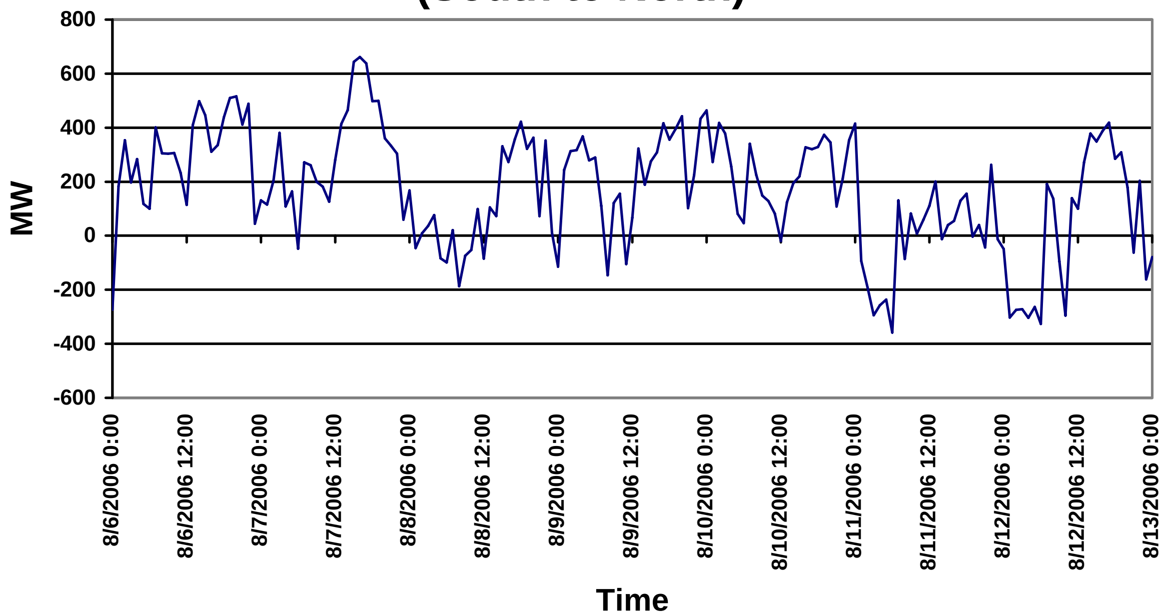
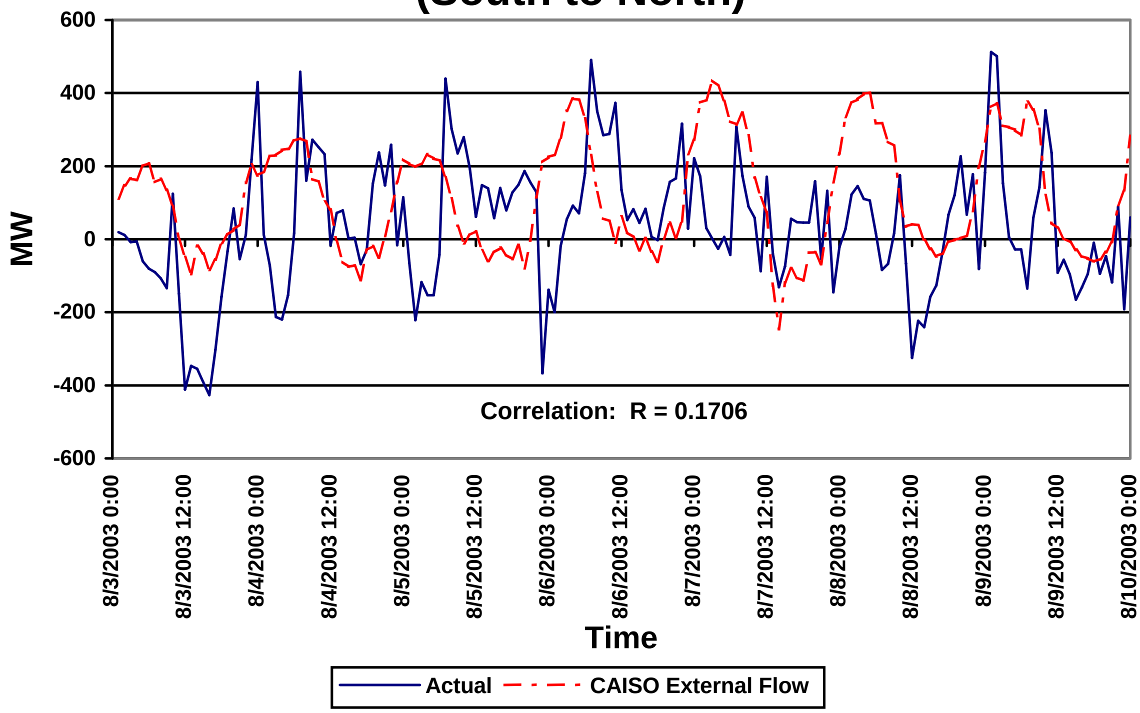


Figure 2: Unscheduled Flow at Malin (South to North)



The lack of a consistent daily pattern of unscheduled flow means that the unscheduled flow is unpredictable without knowledge of the energy schedules from sources to sinks in the western states. One can speculate that knowledge of the schedules submitted in the CAISO's markets could explain much of the flow through the external loop of transmission that is an alternative route between sources and sinks within California. Because LMP Study 3A used a closed-loop model, the CAISO has examined its results to analytically review the Amended Comprehensive Market Design Proposal's conclusion that using a closed-loop model, before modeling data and forward energy schedules are available throughout the western region, may create severe problems. Figure 3 illustrates the LMP Study 3A results comparing the flow through the closed loop outside the CAISO Balancing Authority Area, calculated as the difference between the LMP Study's schedules at Malin/Captain Jack and the flows on the lines across the California-Oregon border, with the actual unscheduled flow at the California-Oregon border, as measured using the CAISO telemetry records. The analysis in Figure 3 shows that the correlation between these two data series is poor (correlation coefficient R = 0.17).[5] In contrast, there are times when the difference between modeled and actual unscheduled flow through the external loop exceeds the difference that results from ignoring unscheduled loop flow, as is implemented in the initial release of MRTU. Thus, the CAISO has concluded that it should not use the closed loop model until adequate modeling data (e.g., resource specific schedules) are available.

Figure 3: Unscheduled Flow at Malin (South to North)



However, LMP Study 3C results show that, at the other extreme, using a completely open-loop model can also result in inaccuracies. Results of LMP Study 3C indicate that, using an open-loop model, congestion on the Palo Verde to Devers line does not match observed flows from actual telemetry data. LMP Study 3C modeled certain months in Winter and Spring 2005, i.e., after the initial phases of upgrades to Miguel substation became operational. As expected, there is less Miguel congestion due to the upgrades. However, as a result of using an open loop model, increased generation near Imperial Valley appeared to

5 A correlation coefficient R of zero means that two data series are completely unrelated to each other, whereas R = 1 means that the data series are perfectly correlated.

provide counter-flow toward Palo Verde, in Arizona, and added to flows from Palo Verde to Devers substation in the Southern California Edison Company area. These resultant power flows on the Palo Verde branch group into the CAISO appeared to flow mostly on the Palo Verde to Devers line. As a consequence, when using the originally-proposed open loop model in LMP Study 3C, the Palo Verde to Devers line became a binding constraint for congestion in many hours. The initial LMP Study 3C results are summarized in the table below:

Month of LMP Study Results	Hours of Miguel Congestion	Hours of Palo Verde – Devers Congestion
October 2004	436	0
November 2004	337	0
December 2004	585	0
January 2005	309	470
February 2005	358	458
March 2005	168	282
April 2005	27	173
May 2005	29	20

As shown, when using the original open loop model, the LMP Study 3C model results in congestion on the Palo Verde to Devers line; congestion that does not match observed flows from actual telemetry. The study results therefore indicate that use of an open loop model can result in less accurate congestion management. Although the Palo Verde to Devers line has been upgraded with higher capacity series capacitors, a large amount of new generation is planned in the Southwest, so this problem could occur in practice under MRTU using the open loop model. The potential impact is not only on the Palo Verde to Devers line: there are now nearby constraints in CAISO Operating Procedure T-175, West of Devers, and Day-Ahead modeling of flows elsewhere in the CAISO that would potentially not match actual Real-Time flows.

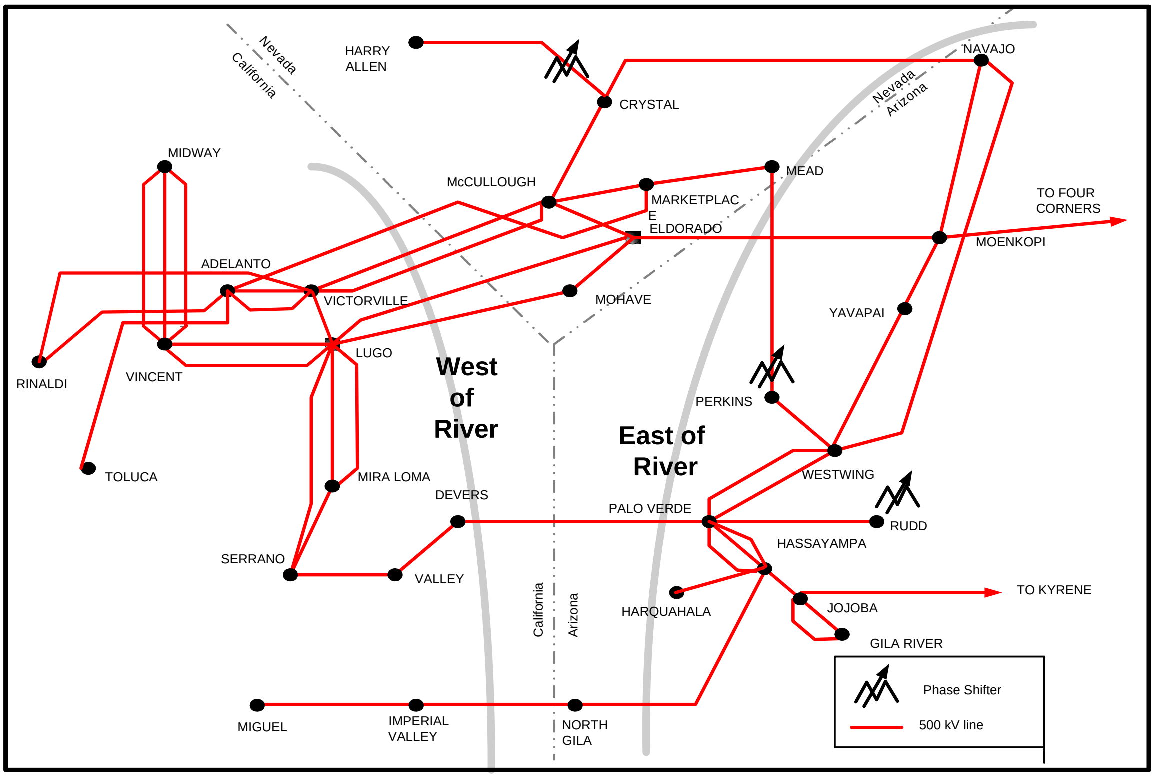
Ultimately, the CAISO will be able to model Arizona and Nevada using MRTU's IBAA functionality or similar methods, including inputs to the market runs that include scheduling information from the neighboring Balancing Authority Areas. This approach will provide the most accurate solution and presumably avoid producing the inaccurate results discussed above. However, the required data will not be available when MRTU begins operation. Thus, in the interim, the CAISO needs an alternate solution.

The remainder of this paper presents and analyzes this alternate solution and demonstrates why this change in the model has been implemented to achieve more realistic congestion management.

Revised Model:

In order to improve the accuracy of the CAISO's MRTU congestion management solutions, the CAISO has added four 500 kV lines to the original open loop MRTU FNM. Figure 4 shows the full set of 500 kV transmission lines in the area that is the subject of this revised model.

Figure 4: Existing Physical 500 kV Transmission System for East-Of-River, West-Of-River, and Related Lines

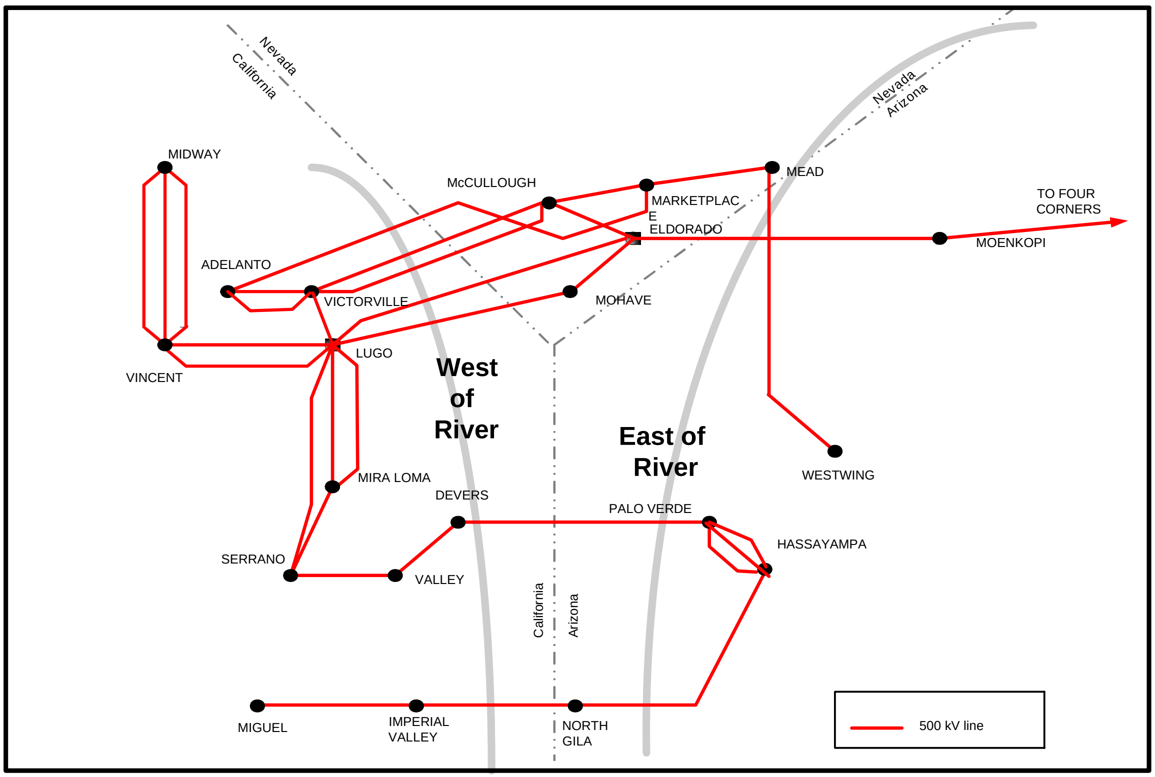


Only a portion of this network was originally represented in the market FNM for MRTU, consisting of (1) radial branch groups to Scheduling Points, (2) external connections among the lines that comprise individual branch groups (e.g., Palo Verde is connected to Hassayampa because the intertie lines to these two points comprise the Palo Verde branch group), even though scheduling rights under CAISO operational control include only the intertie lines and not the external lines, and (3) a looped network made up of lines on which Southern California cities have scheduling rights that have been converted to CAISO operational control (i.e., CAISO Controlled Grid that is outside the CAISO Balancing Authority Area, known as the "New PTO" network).[6] The original market FNM for MRTU did not include branches that are beyond the CAISO Balancing Authority Area and CAISO Controlled Grid, except for connections within otherwise radial branch groups.

[6] The portion of the "New PTO" network shown in Figure 4 consists of the lines from Victorville to Adelanto, Adelanto to Marketplace, Victorville to McCullough, McCullough to Marketplace, Marketplace to Mead, and Mead to Westwing. There are also 230 kV and 345 kV lines in the New PTO network, which are not shown in Figures 4, 5, and 6.

The portion of the 500 kV network from Figure 4 that was originally included in MRTU's market FNM is shown in Figure 5.[7]

Figure 5: 500 kV Lines in Original MRTU Market FNM (CAISO Grid and Interties, New PTO Network, and External Branch Group Connections)



The modification presented here is to add four lines to MRTU's original market FNM, for reasons discussed in this paper, consisting of:

- Two lines from Palo Verde to Westwing,
- One line from Westwing to Yavapai, and
- One line from Yavapai to Moenkopi.

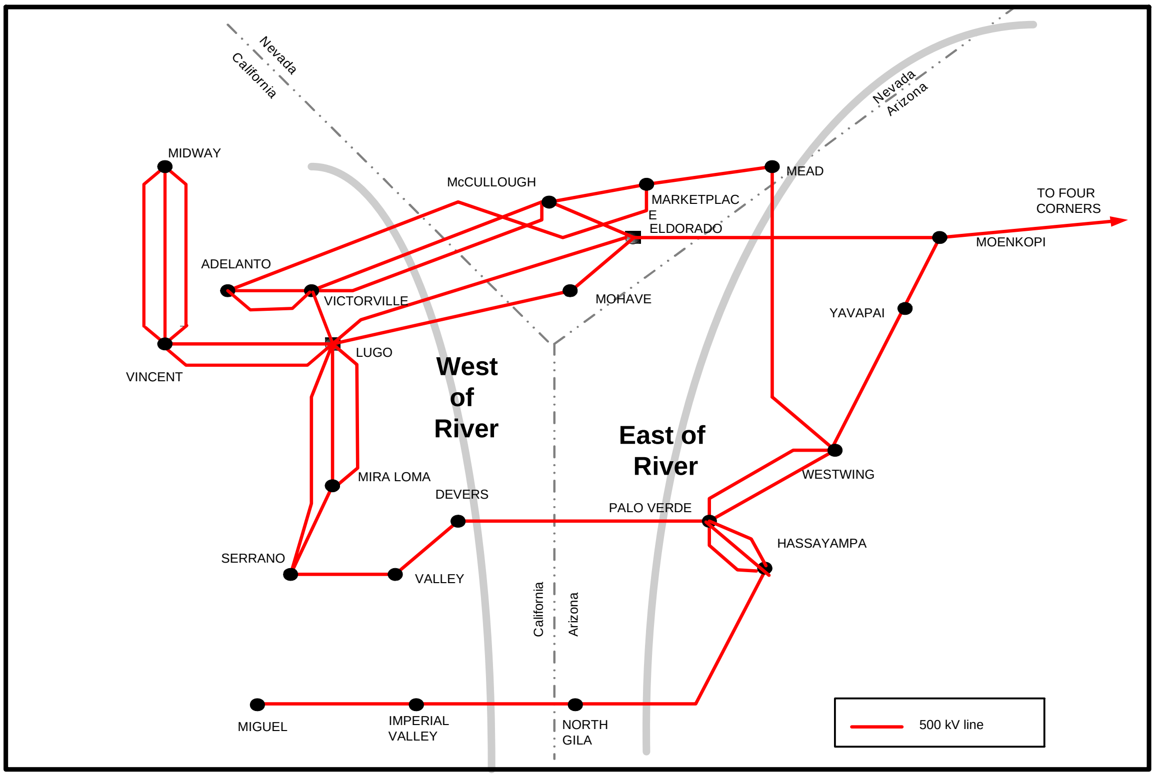
Because of the mechanics of matching modeled flows in the Real-Time Market (RTM) with the State Estimator solution, this modification also includes adding a 500 kV substation at Yavapai, including a fictitious generator to model injections into the network.[8]

[7] A detail that is not shown in Figure 5 is that because Schedules cannot cross between the Southern California cities' Converted Rights to and from McCullough substation, and rights included in the CAISO Controlled Grid to a McCullough Scheduling Point via the Eldorado transmission system (brought under CAISO operational control when Southern California Edison originally joined the CAISO), the market FNM creates two McCullough 500 kV buses (one connecting to other New PTO Scheduling Points, and the other connecting to El Dorado) that are not normally connected to each other. Note that since inclusion of lines among Palo Verde, Westwing, and Moenkopi that affect flows at these and other Scheduling Points but that do not have contract capacity under CAISO operational control, this modification also connects the lines at McCullough, for the purpose of modeling flows. The separate scheduling of contract paths with other Balancing Authority Areas will not change by modeling the system in this manner.

All of these facilities are actual facilities in the physical network, although they (like other parts of the New PTO network) are represented in the FNM as part of a "market only" network model that is different from the network model used in EMS for the area external to the CAISO Balancing Authority Area. The EMS network model is used as part of the market FNM within the CAISO Balancing Authority Area and on interties across the CAISO Balancing Authority Area boundary.

Figure 6 shows the resulting network with these lines and substations added to Figure 5's network.

Figure 6: Revision for 500 kV Lines in MRTU Market FNM



The addition of these lines and substations does not change the CAISO's Scheduling Points for the MRTU market, and does not change scheduling practices. Tagging will use the same definitions of Scheduling

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8 In RTM, the market software system receives the State Estimator solution data that enables the market system to match MW flows on interties across the CAISO Balancing Authority Area boundary, but does not use the State Estimator solution for external Balancing Authority Areas. The market system contains fictitious generators (System Resources) at each external Scheduling Point (including New PTO Scheduling Points), and calculates a set of injections from which the calculated MW flows across the Balancing Authority Area boundary match the State Estimator solution. (Withdrawals are simply injections of negative MW quantities.) From the calculated total injection at each Scheduling Point, the market system subtracts the CAISO market schedules and considers the balance to be compensating injections, which represent unscheduled flow as well as schedules in external balancing Authority Areas that are unknown to the CAISO.

Since the original MRTU network model had a simple radial connection from Mead to Westwing, the calculated injection at Westwing did not need to reflect interactions with any flows except at Mead. However, with an additional connection to Moenkopi, the additional point of injection at Yavapai may be needed to achieve a successful calculation of compensating injections. Because there is a substation at Yavapai, actual flows at Westwing toward Moenkopi will not match actual flows at Moenkopi coming from Westwing, and the injection at Yavapai represents the difference.

Points as would otherwise be used[9]. There is also no change in the MRTU market software (since the New PTO functionality already exists and would be used for this extension of the New PTO area). This change affects only the market FNM that is provided to the market systems. The existing branch group definitions for MRTU have been revised to add the new lines, using the system of branch group definitions that has been defined for the New PTO network, as documented in http://www.caiso.com/185d/185db75028b00.pdf.

Validation of the Expanded Model:

The following analysis demonstrates the merit of this modification to the market FNM by comparing LMP Study results for flows on major lines to the actual flows in an illustrative hour. In the LMP Study results for May 2005 conditions (to be published when other model results for this month are complete), one hour when the Palo Verde to Devers line would be a binding constraint if the original open-loop model were used is May 4, Hour 19. Figure 7 shows the actual flows for this hour, from actual telemetry. The rating at this time (prior to upgrades of series capacitors on the Palo Verde to Devers line) was 1645.5 MVA. The average flow for this hour was 1150 MW and 1155 MVA -- quite a bit less than the capacity.

Figure 7: Actual Flows for 5/4/05 Hour 19

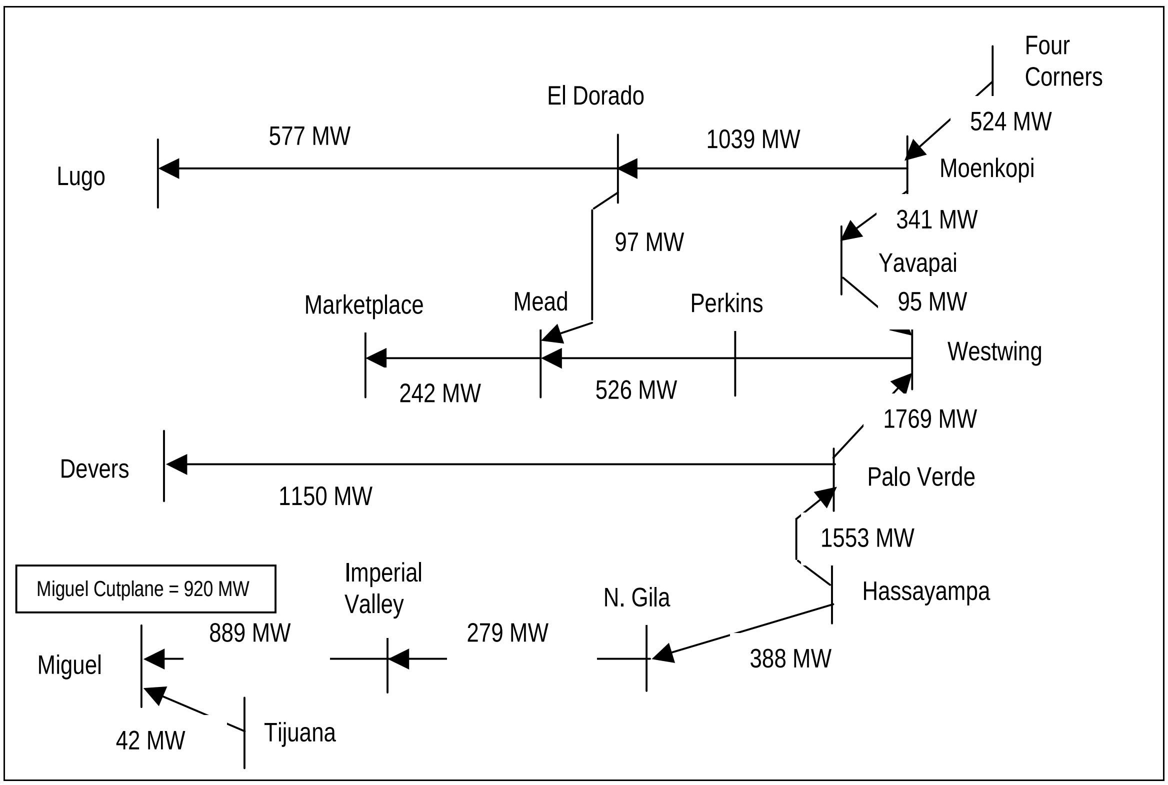

Figure 8 shows the original LMP Study results for the same hour, using the current "open loop" market network model configuration.

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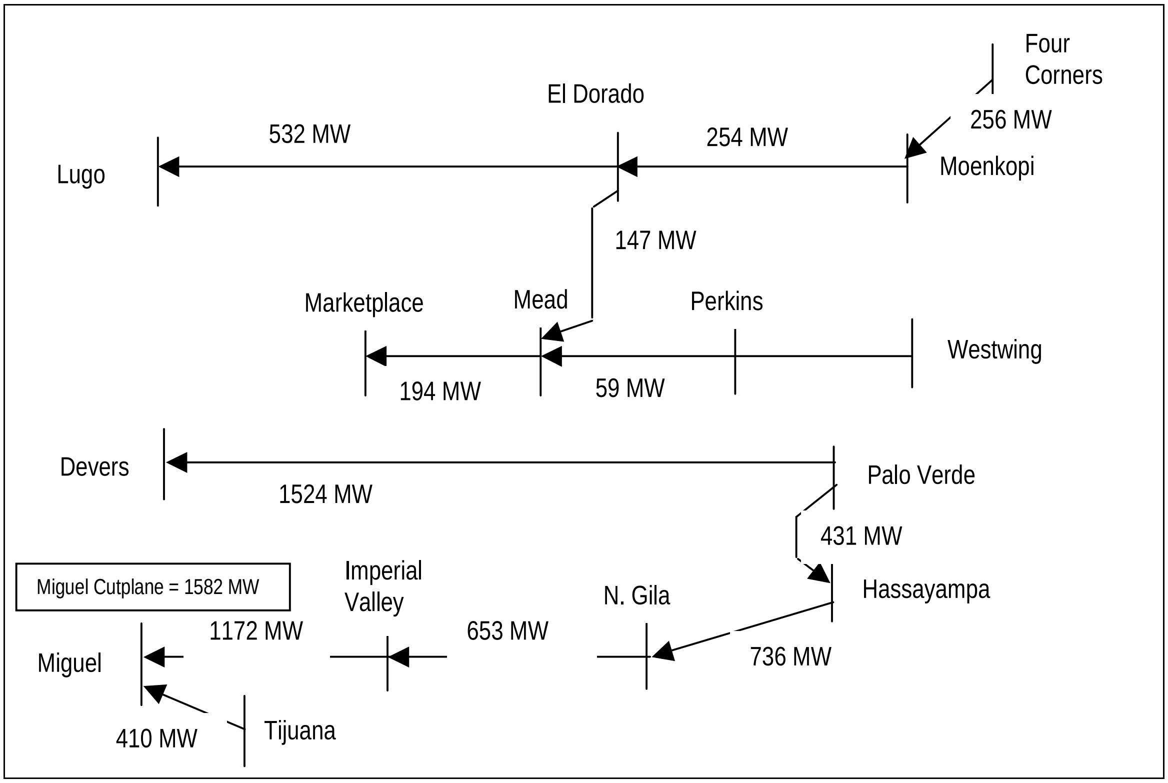
[9] Note that scheduling and settlement at Palo Verde and Hassayampa are aggregated at the PVWEST Scheduling Point which is effectively a hub.

Figure 8: Modeled Flows for 5/4/05 Hour 19, with Open Loop

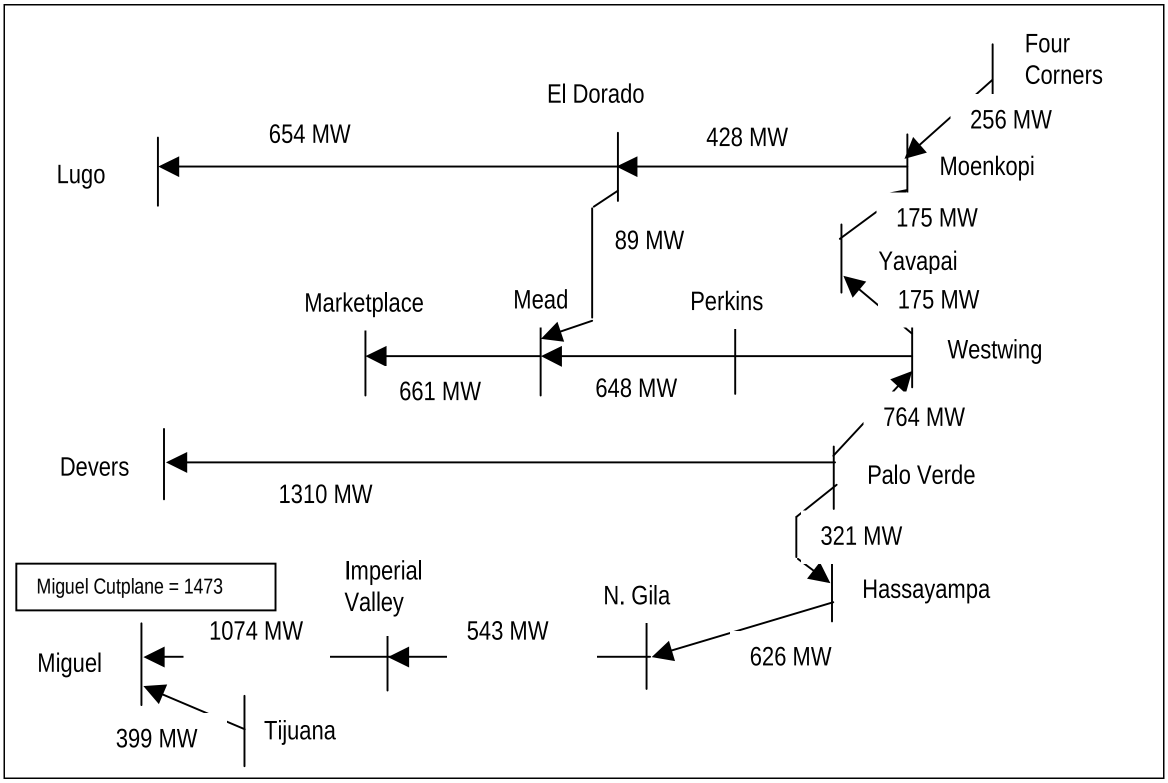


Comparing Figures 7 and 8, the Palo Verde to Devers flow is at the capacity of the line in Figure 8 even though there was adequate remaining capacity in Figure 7.[10] Dispatch using Optimum Power Flow is running the generation near Imperial Valley at a higher output than the CAISO's dispatch did historically, which results in higher flows into Miguel substation. The Miguel Cutplane flow of 1582 MW is close to the limit of 1600 MW that was used in LMP Study results for May 2005, after some Miguel upgrades were in service but before the new Miguel to Mission 230 kV line began operation. Overall, there are several differences in line flows between the actual flows in Figure 7 and the modeled flows in Figure 8 using the open-loop network model.

Figure 9 shows final LMP Study results for the same hour, using the revised "partial loop" market network model configuration.

[10] The LMP Study model has higher reactive flows than actually occurred, due to differences in voltage regulation, so the modeled MW flow is lower than the MVA flow. In case there is curiosity whether loop flow modeling in the LMP Study is causing the congestion from Palo Verde to Devers, note that for this hour, the LMP Study inputs include 124 MW of north-to-south loop flow through the CAISO for this hour, as measured at Malin. The sink for the LMP Study's modeling of loop flow is Palo Verde, so the loop flow in this hour is actually counter-flow that would help to relieve the congestion from Palo Verde to Devers.

Figure 9: Modeled Flows for 5/4/05 Hour 19, with Partial Loop

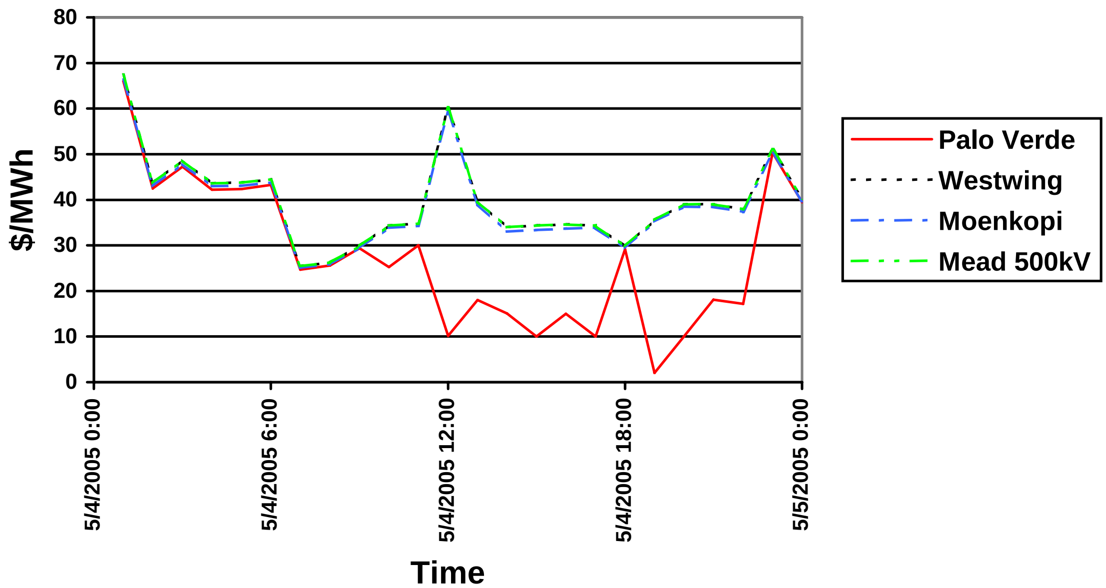


The result of adding the four lines to the network model is that the flow on the Palo Verde to Devers line is less than the line rating, as it is in the actual conditions. The Imperial Valley generation is about the same in Figure 9 as in Figure 8, but the Miguel Cutplane flow has more headroom before it would be a binding constraint. Generally, the modeled flows in Figure 9 are closer to the actual flows than they are in Figure 8, even though the result is not a perfect match because the model does not include scheduling information for other Balancing Authority Areas.

Appendix A includes certain illustrative graphs comparing the actual flows with modeled flows for the open loop and partial loop models for all hours of May 4, 2005. The conclusion is the same as from comparing Figures 8 and 9, that the partial loop model is an improvement in having the MRTU network model reflect actual conditions. This occurs even though the market network model does not have scheduling information for other Balancing Authority Areas (except for transactions with the CAISO), as would be available if Arizona and Nevada could be modeled more fully as IBAAs. In other words, while the partial loop model differs from the preferred IBAA model in that it does not attempt to represent the physical resources backing imports as being located anywhere other than at the boundary Scheduling Point, the partial loop model is an improvement over the open loop model. Developing the necessary arrangements and information to implement a more detailed IBAA model is the best long-term solution and the CAISO is committed to further dialogue with all affected balancing Authorities so as to implement the preferred approach. In the interim, the partial loop network model appears to be a workable solution to the issues raised by use of an open loop model.

A remaining question concerning the addition of the four lines described in this paper is whether the resulting LMPs are acceptable without adding them, compared to LMPs after including them. Figure 10 shows the LMPs that would result from the open loop model. The Palo Verde to Devers branch rating is a constraint during several hours in the LMP Study results for May 4, 2005, with LMP differences of up to $50/MWh compared to other Scheduling Points in the Southwest such as Mead, Moenkopi, and Westwing. A concern is that if there is a risk that these LMP differences could occur in the MRTU market, Market Participants could be discouraged from offering Bids at Palo Verde, where a large amount of capacity is available for imports into the CAISO.[11] These LMP differences are probably unrealistic, because offering a Bid at Palo Verde does not mean that the underlying resource is actually at Palo Verde – it could be anywhere in the Southwest, and the Market Participant has simply obtained contract capacity from the true source to the Scheduling Point at Palo Verde.

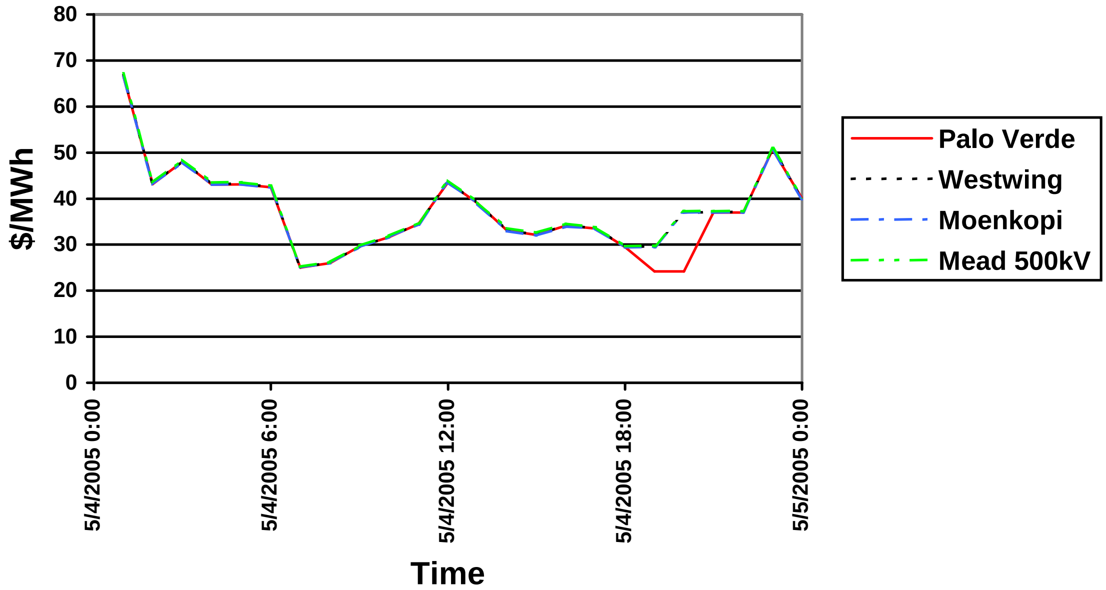
Figure 10: LMPs with Open Loop Model



In contrast, Figure 11 shows the LMPs using the partial loop model, with other inputs being the same as in Figure 10. The LMPs are essentially the same at these four Scheduling Points, except for two hours where there really were more economically-viable bids offered at Palo Verde and Hassayampa than could be scheduled within the Palo Verde branch group's scheduling limit. The similarity is a more realistic view of flow patterns and transmission scheduling, where the actual source of generation underlying an intertie Schedule could be anywhere in the Southwest, and its output would flow throughput the network to multiple intertie lines into the CAISO. A Market Participant would arrange for contract capacity through other Balancing Authority Areas, based on conditions within those Balancing Authority Areas, to a Scheduling Point into the CAISO, and the CAISO would be relatively indifferent as to which Scheduling Point is used, when the true source of generation in unknown, up to the point where the contract capacity is fully subscribed.

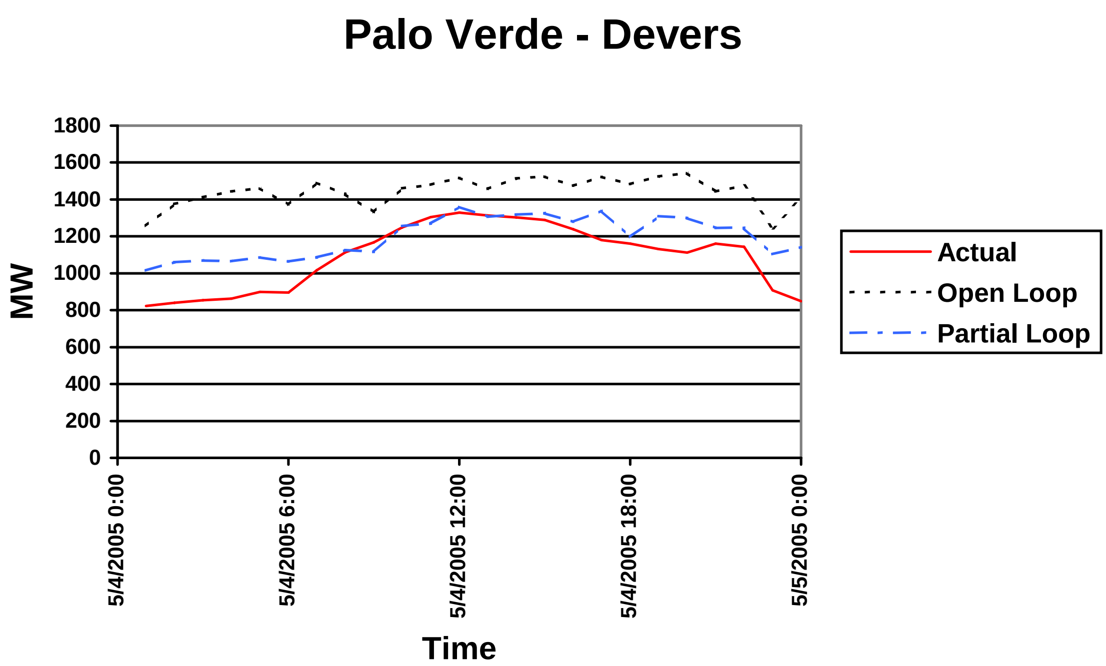
11 Instead of receiving import Bids as the CAISO desires, the market might get a number of Day-Ahead export bids at Palo Verde that are seeking inexpensive energy. When Real-Time comes and use of the State Estimator solution corrects the incorrectly-modeled flows, the CAISO would be committed to serve the exports.

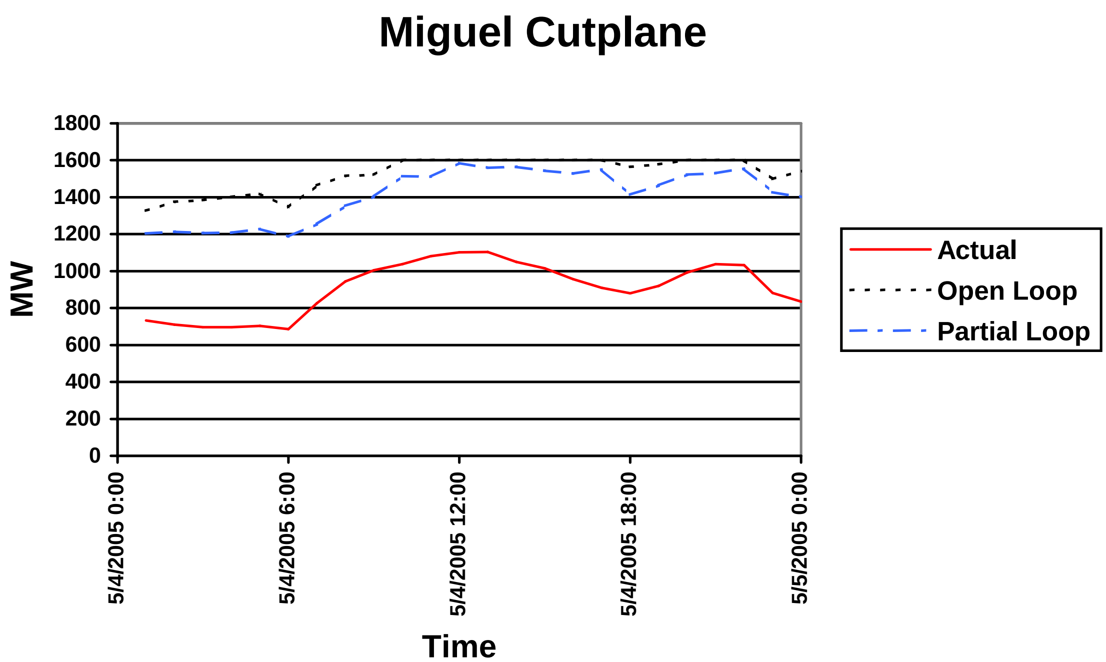
Figure 11: LMPs with Partial Loop Model



Appendix A: Detailed Comparison of Open Loop and Partial Loop Model Results with Actual Flows

The following graphs add to the analysis presented in Figures 7 to 9, by comparing hourly flows for all hours of May 4, 2005, with actual flows from actual telemetry for critical transmission constraints that are the most directly affected by adding the partial loop model. In most cases, the partial loop model's results are closer to the actual flows than the open loop model's results.

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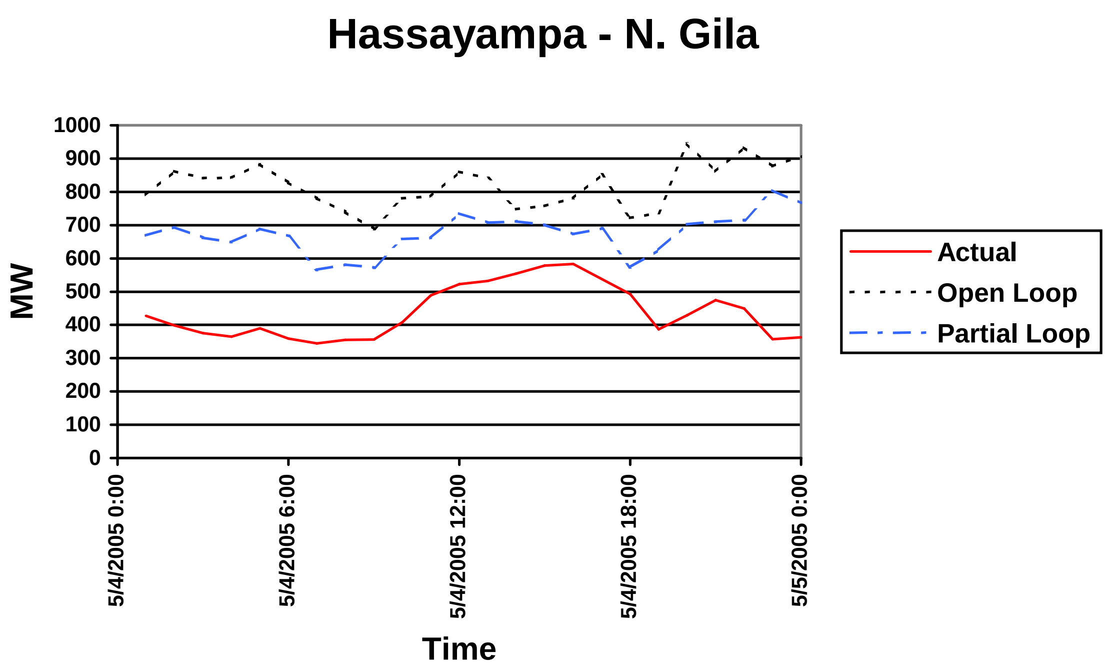
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