Appendix 3: DETAILED STUDY METHODOLOGY

Detailed Study Methodology
for Generation Deliverability Study

This document describes the detailed methodology that has been used in the preliminary California ISO generation deliverability study. The document is divided into four main sections covering the main concepts and techniques of the study process. Section 1 explores the generation deliverability concept, technical difficulty while attempting to determine deliverability problems, and the overview of the entire study methodology. Section 2 explains the screening process that filters scenarios with potential deliverability problems from the massive number of scenarios. Section 3 focuses on the verification process which deliverability problems from potential scenarios will be confirmed. At the end of this document, Section 4 concentrates on the study results and explains each section of deliverability report.

1) Overview of Deliverability Study

The basic concept of generation deliverability study is the ability to look for potential transmission planning and operating reliability criteria violations associated with dispatch of generators. The ISO proposed deliverability methodology narrows the scope of the deliverability assessment to scenarios when there is the capacity reserve shortages, which are expected to occur during the summer peak load period. During this time period it is assumed that all available generation would be dispatched to serve load regardless of cost. It is also assumed that there is sufficient generation producing in the load pockets. Instead of looking at several “snapshot” scenarios of the system, deliverability study searches for potential problems among millions of scenarios created by the variation of generation dispatch, contingencies, and limiting facilities. As a result, deliverability study could reveal reliability problems that never been found during the regular planning process. In addition, the methodology for varying the generation must be well defined so it can be consistently applied across the ISO system and from one generator interconnection study to the next, and limited to reasonably expected scenarios. The PJM Deliverability Assessment methodology was used as the starting point for developing the California ISO proposed deliverability methodology.

In general, scenarios for generation deliverability can be created from the combination of the following factors.

- Contingencies: Loss of single or multiple elements according to NERC category B or C outages.
- Generation Dispatch: Any changes in output (increasing or decreasing) of single or multiple generators in the study area that might impact power flow on the facilities.
- Branch Group Flows: Branch Groups represent the transmission paths between California ISO Control Area and the neighboring systems. Branch Group flows in the base case were based on historical imports during summer peak. Existing transmission contracts not scheduled in the base case could be scheduled during the development of stressed scenarios.
Appendix 3: DETAILED STUDY METHODOLOGY

Example of how different scenarios can be created can be demonstrated by looking at a sample 5 buses power system as shown in figure 1. In this example, even though the system has only 5 buses, 4 lines, and 1 transformer, 47 scenarios can be created from combining the following parameters:

- Contingencies only create 15 different scenarios (5 for N-1 and 10 for N-2 common mode failures)
- Generation dispatches only create 2 different scenarios.
- Combination of contingencies and dispatches create 30 different scenarios.

Following the same approach shown in this example, combined events for a full-loop power flow base case will easily reach millions of scenarios. A generation deliverability study needs to analyze these scenarios to search for transmission overloading problems.

Large numbers of study scenarios make it almost impossible to analyze every case using non-linear AC power flow analysis. For this reason, this deliverability study has adopted a screening technique to select only the scenarios with potential deliverability problem that limit the deliverability of generator capacity from all scenarios with much faster speed\(^1\). The mechanics behind this screening process is the implementation of linear analysis that does requires repetitive non-linear AC power flow solution for each study scenario. Then the impacts from any changing parameters can be calculated using appropriate distribution factors. More details of the screening process will be covered in section 2.

After the screening process has selected potential scenarios from all scenarios, these scenarios will need to be verified to ensure the existence of deliverability problems. The main

\(^1\) This methodology for assessing deliverability has been developed from consultation with PJM engineers
Appendix 3: DETAILED STUDY METHODOLOGY

purpose of this secondary process is to eliminate any mismatches that might occur from adopting the linear analysis technique. During the verification process, AC power flow will be used to confirm deliverability problems in each case as well as other techniques could be implemented to obtain additional useful information. The details of verification process will be discussed in section 3 and the summary of the deliverability study process is shown in figure 2.

As seen from the overview of the study concept, the underlying benefits from this 2-step approach is the ability to identify deliverability problems from massive number of scenarios in much shorter time while the accuracy of results will not be compromised. Since the final determination of deliverability relies on AC power flow, the problems reported by the study will not be based on the approximation technique and will reflect the impact from both real and reactive power flow.

![Figure 2. Overview of the deliverability study processes](image)

DRAFT 4/12/05
2) Screening Process

Section 1 of this document has highlighted the importance of the screening process as a key tool to minimize the number of scenarios that will be sent to the verification process. Generally, a good screening process should reject most scenarios that cause no deliverability problems. However, it is imperative that the screening process should not be too sensitive and rejects too many scenarios that might include some scenarios with deliverability problems.

Linear analysis has been used in the screening process. It is an analysis technique well known to power industry for quite sometime. The product such as Transmission Loading Relief (TLR) is an example of linear analysis applications in modern electricity market. In a nutshell, linearization technique assumes that superposition theory can be used and there is no nonlinearity of output in the system. Consequently, regardless of how many scenarios the study has, linearization requires only one non-linear AC power flow solution and distribution factors for future calculations. Then, since the impact on the system is assumed to be linear, the impact on the system can be determined using distribution factors. For example, once the generation shift factor (GSF) of a generator over a transmission line has been calculated, the impact from any level of output from this unit over a transmission line can be estimated without the need to obtain a new power flow solution.

There are a number of distribution factors have been developed for different purposes. This document will focus on three distribution factors related to deliverability study. The basic concept of these factors is explained in section 2.1-2.3.

2.1 Generation Shift Factor (GSF)

Generation Shift Factor is a distribution factor that can be used to estimate the impact from the shift of a generator’s output over a transmission facility. Basically, GSF determines percentage of the change at generator’s output that will appear over the facility. For example, assuming the same 5 buses power system as shown in figure 1. Given GSF\(_{2,34}\) is the GSF of the impact from generator at bus 2 over this transmission line 34. The impact from the incremental of output from generator at 2 over this line can be calculated by the following formula.

\[
\text{Impact from generator} = (GSF_{2,34})(\Delta P_2)
\]

Where

\[GSF_{2,34} = \text{Generation Shift Factor of generator at bus 2 over line 34}\]

\[\Delta P_2 = \text{The amount of MW output change from generator at bus 2}\]

This example shows the efficiency of using GSF to estimate power flow on transmission facilities without the need to get a new power flow solution. In this case, once GSFs have been calculated, the impact from any variation of generator output can be obtained from simple arithmetic equations. The same context can be used when focusing on the impact over a transmission line from multiple generators are moving their outputs.

---

2 The purpose of these sections is to provide the basic concept of the methodology. The commercial software package may implement different technique to enhance the capability of the program.
2.2 Line Outage Distribution Factor (LODF)

Estimation of impact from an outage over a facility can be done using Line Outage Distribution Factor (LODF). In general, an outage impacts the system by transferring the amount of power flowing on the outaged elements during pre-contingency conditions to other facilities in the system. These changes could increase or decrease power flow on the facilities depending on network topology, load, and generation dispatch.

LODF was formulated as a percentage of pre-contingency flow on the outaged line that appears on the monitoring facility during contingency conditions. Example of the utilization of LODF is shown from considering an example network shown in figure 3. The outage of line 34 will result in the distribution of pre-contingency flow on this line \(P_{34}\) to the rest of the network. From this example, the impact over line 12 from the outage of line 34 can be calculated from the following formula:

\[
\text{Outage Impact} = (LODF_{34,12})(P_{34})
\]

Where

\(LODF_{34,12}\) = LODF over line 12 from the outage of line 34

\(P_{34}\) = Power flow over line 34 during pre-contingency conditions

2.3 Outage Transfer Distribution Factor (OTDF)

The concepts of GSF and LODF give us an idea of how the impacts from generation dispatch and outage can be estimated without repeatedly obtaining new power solutions. However, these two indices do not address the cross-relationship between generator dispatches and outages. This makes the estimation of any scenario involving both contingency and generator dispatch more complicated and becomes a time-consuming process. Example of this scenario is shown in the situation when the contingency of line 34 occurs after generator at bus 2 has increased its output by \(\Delta P_2\) MW as shown in figure 4. In this case, incremental output generator 2
will impact power flow not only the line 12 but all lines in the network. Power flow during pre-contingency conditions become \( P_{12} + (GSF_{2,12}) (\Delta P_2) \) for line 12 and \( P_{34} + (GSF_{2,34}) (\Delta P_2) \) for line 34. Consequently, the estimation of impact from contingency of line 34 using LODF must based on \( P_{34} + (GSF_{2,34}) (\Delta P_2) \) instead of \( P_{34} \) in order to capture the parallel impact from generation dispatch.

![Diagram of a power system with high generation dispatch under contingency conditions](image)

**Figure 4: A power system with high generation dispatch under contingency conditions**

As seen from this example, the complication of using GSF and LODF has led to the creation of OTDF which represents the combined impact from generation dispatches and outages. Formulation of OTDF was based on GSF and LODF and the impact from the transfer from generator 2 over line 12 under the contingency condition of line 34 can be calculated from equations below.

\[
OTDF_{34,12} = \Delta P_2 \times [GSF_{2,12} + (LODF_{34,12} \times GSF_{2,34})] \\
\text{Combined Impact} = (OTDF_{34,12})(\Delta P_2)
\]

Where

\(OTDF_{34,12}\) = Outage Transfer Distribution Factor on line 12 if line 34 is out-of-service

After the distribution factors become available, it’s fairly simple to use these factors to estimate the impact over a facility under various conditions. The basic concept of using the distribution factors is to select the right factor for each scenario. Table 1 shows how different distribution factors should be applied for various scenarios (DFAX is used as a general term to represent to appropriate distribution factor for each scenario).
Appendix 3: DETAILED STUDY METHODOLOGY

Table 1. Selection of distribution factors for different study scenarios

<table>
<thead>
<tr>
<th>Generators Output</th>
<th>System Conditions</th>
<th>Distribution Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchanged</td>
<td>Normal</td>
<td>N/A</td>
</tr>
<tr>
<td>Changing</td>
<td>Normal</td>
<td>GSF</td>
</tr>
<tr>
<td>Unchanged</td>
<td>Contingency</td>
<td>LODF</td>
</tr>
<tr>
<td>Changing</td>
<td>Contingency</td>
<td>LODF, OTDF</td>
</tr>
</tbody>
</table>

2.4 Screening Process using Linear Analysis

Section 2.1- 2.3 shows the effectiveness of implementing linear analysis to estimate the impact from any changing parameters as a part of deliverability study. The main benefit of using this method is the significant reduction of computation time for screening process. Generally, millions of scenarios can be screened in the matter of minutes.

California ISO uses the Managing Utilizing System Transmission (MUST) software package for the screening process. The study uses the Generator Sensitivity Analysis (GSA) feature of this software to create all scenarios, calculate DFAX, and identify potential problems. The list below summarizes the MUST user options chosen and some special base case modifications for the deliverability study:

- Ratings of each facility in the base case were scaled to 96% of its base case values. This is necessary to compensate for the overlapping export and import subarea selections used in MUST. This inaccuracy is small because the generation pockets are small compared to the overall ISO system. The 96% derate is expected to overcompensate for the inaccuracy. In addition, the MUST option for reducing line ratings to account for reactive flows was selected. Performing the study with lower ratings is expected to overestimate the known inaccuracies and ensure the reporting of all scenarios with potential deliverability problems.

- Unused existing transmission contracts on Branch Groups were modeled as offline generators available to come on-line, connected to the grid at the control area boundary points. In addition, 1 MW offline generators were modeled on Branch Groups with schedules but fully used existing contracts. This technique allows the program to report branch groups that contributing to deliverability problems. This information will be useful for the future study.

- The study analyzes the system under normal and NERC categories B and C contingencies conditions. It also takes Special Protection Schemes and Remedial Action Scheme into consideration for the accuracy of results.

- In each scenario, only generators with DFAX on the monitored facility greater than 2% were adjusted in the analysis. According to the methodology, the impact from generators with DFAX less or a flow impact (i.e. Pmax*DFAX/facility rating) less than 5% can be considered as minimal and negligible.

- The study searches for potential problems over transmission facilities at the voltage level 60 kV and above.

3 Assumption of generator’s output for the study. Unchanged represents the situation does not involve moving of generator’s output. Changing represents the scenarios that vary generator’s output that might.
Applying the above techniques, the screening process selects the scenarios that deliverability problems have been found using the linear analysis technique. After the screening process is completed, the selected scenarios along with the following information for each case will be provided to the verification process.

- Facilities (transmission lines or transformers) that could encounter deliverability problem.
- Details of the contingency that cause deliverability problem (in case that the problem involves contingency).
- Details of Special Protection Scheme and Remedial Action Scheme (if applicable to the contingency).
- Distribution factors of all units that impact the limiting facilities. This includes the units that exacerbate or relieve deliverability problems.

The figure 5 below shows the overview of screening process.

![Screening Process Diagram]

**Figure 5 Summary of the Screening Process**

### 3) Verification Process
The verification process is the final step of deliverability study. It was designed to confirm deliverability problems from scenarios that have been found during the screening process. Since the screening technique employs linear analysis technique to speed up the calculation with reduced facility ratings, this process has tendency to overestimate the overloads. For this reason, all the results from the screening process are verified by AC power flow at 100% facility ratings to ensure the deliverability problems are credible. In brief, the main purpose of this process is to ensure the accuracy of study results and to apply the specific ISO Deliverability Methodology to the set of scenarios identified by MUST. Summary of the verification process is shown in figure 6.
During the course of the study, California ISO has developed an EPCL program MUST.P as the main engine for the verification process. This software automatically reads information from screening process, performs all verification process, and has an ability to perform additional study such as generation capacity reduction. The outputs from this software are given in full text report and/or the database formats that supports easy data manipulation and better future references. Since this EPCL has simulated all the techniques for verification process, this section will be dedicated to explaining the mechanisms behind this program.

AC Verification Process and ISO Deliverability Methodology

Overloaded Facilities  | Contingency details  | SPS/RAS details  | Generators that contribute to the overloads

Scenarios with Potential Deliverability Problems

Scenarios with Confirmed Deliverability Problems

Figure 6. Summary of the verification process

3.1 Simulating Stressed Generation Dispatch Scenarios

The outputs of units with a DFX or a flow impact ratio greater than 5% are increased starting with units with the largest flow impact on the transmission facility. The flow impact is defined as the DFX * (Pmax) and the flow impact ratio is the ratio of the flow impact divided by the rating of the facility. No more than twenty^4^ units are increased to their maximum output. In addition, no more than 1500 MW of generation is increased. All remaining generation within the Control Area is proportionally displaced, to maintain a load and resource balance. The number of units to be increased within a local area is limited because the likelihood of all of the units within a local area being available at the same time becomes smaller as the number of units in the local area increases. The amount of generation increased also needs to be limited because decreasing the remaining generation can cause problems that are more closely related to a deficiency in local generation rather than a generation deliverability problem.

---

^4^ The cumulative availability of twenty units with a 7.5% forced outage rate would be 21%--the ISO proposes that this is a reasonable cutoff that should be consistently applied in the analysis of large study areas with more than 20 units.
Appendix 3: DETAILED STUDY METHODOLOGY

For study areas where the 20 units with the highest impact on the facility can be increased more than 1500 MW, the impact of the remaining amount of generation to be increased will be considered using a Facility Loading Adder. The Facility Loading Adder is calculated by taking the remaining MW amount available from the 20 units with the highest impact times the DFAX for each unit. An equivalent MW amount of generation with negative DFAXs will also be included in the Facility Loading Adder, up to 20 units. Negative Facility Loading Adders are set to zero. Example of Facility Loading Adder is shown in figure 7.

3.2 Simulating Contingency

After reading all information from screening process, MUST.P simulates contingency by switching the status of transmission facilities or generators. The contingency list (obtained from PTOs) contains NERC category B or C contingencies that involve the outages of single or multiple facilities in the system. However, the program will skip this step if the screening process indicates deliverability problems under normal conditions.

3.3 Simulating SPS and RAS

If a contingency activates an existing or planned Special Protection System or Remedial Action Scheme, this scheme will be simulated during the verification process. The actions taken by these schemes might involve tripping single or multiple transmission facilities, generators or dropping the load.

3.4 Re-dispatching Generators During Contingencies

Generators will be re-dispatched during contingencies if the contingency includes generation or load tripping or if losses change more than a certain amount. This re-dispatch is based on simplified version of the WECC governor power flow methodology to generators in WECC area. This scheme is used to rebalance the power after the outages of generators and/or load caused by contingencies or remedial actions (RAS/SPS). The outaged MW will be distributed to all generators in WECC. The program re-dispatch is based on WECC area response factors observed during a detailed WECC governor powerflow simulation.
The example seen in figure 7 shows Facility Loading Adder (FLA) is activated when the accumulated output from generators exceeds 1,500 MW (up to the point where generator E is dispatching at 277 MW). The impact from moving 1,500 MW resulting in 105.12% loading on the monitored element as seen in line 157. The estimated impact from FLA is calculated by:

- Adding the impact from the remaining generators in the top 20 (line 140).
  New flow = $-1393.64 + (-60.7151) = -1454.35$ MVA

- Deducting the impact from the dispatch of units with opposite DFAX (balancing)
  New flow = $-1454.35 + 26.3230 = -1428.04$ MVA

As seen from line 158, power flow from FLA is estimated at $-1428.04$ MVA or 107.72% of facility rating.

3.5 Generation Capacity Reduction

Generation Capacity Reduction (GCR) is an optional process used to quantify the MW curtailment from generators. It calculates the amount of undeliverable MW of generators based on their contribution to the problem, to ensure that power flow on the monitored facility will not exceed its applicable ratings. At this point, the ISO has included an interim version of GCR scheme in the verification process as a guideline of how the calculation could be done and to access the magnitude of undeliverable MW in the preliminary study. The final methodology for GCR would be determined based on the input from stakeholder process.
Appendix 3: DETAILED STUDY METHODOLOGY

4) **Generation Deliverability Results**

   This section explains the results that will be given in the report created by MUST.P. For each deliverability problem, MUST.P program produces a detailed report describing the problems as shown in figure 8-9. This report can be divided into 7 parts as follow.

   1) Monitored facility and power flow on this facility under normal conditions

   2) Contingency with the details.

   3) Power flow on the monitored facility after contingency with the base case dispatch. If the contingency involves generator dropping, this will represent power flow after the re-dispatching scheme has been done.

   4) Stressed generation dispatch shows up to 20 units with adverse impact on the monitored facility (line 119-123). In some cases, this list may show the units with opposite distribution factors from power flow on the monitored line. In this situation, the study has found a deliverability problem that caused by the stressed dispatch that reverses power flow on the monitored facility. The example in figure 8 also shows the scenario when Facility Loading Adder was activated (line 127-146)

   5) Summary of units that pass the screening process and units that were included in the worst dispatch. RTR 986 is assigned to units that significantly impact power flow on the monitored facility based on the screening criteria specified in the straw proposal (5% DAFX).

   Zone 986 represents the units in the top 20 that create worst dispatch. The number of units assigned to zone 986 is always less or equal to units with RTR =.986.

   6) Summary of final re-dispatching scheme after moving the generators

   7) Reports of final power flow on the monitored facility after all processes have been done.

   8) Optional and based on the tentative approach: The reports show generation capacity reduction as shown in figure 9.

   When looking at the deliverability report, it is imperative to understand that it simulates the scenarios where contingency has occurred in the system with the generators already producing their output at the stressed dispatch scenario. Result shown in figure 8 is a good example of how generation dispatch can cause reliability problem that cannot be seen simply by applying contingency. The outage itself will not result in reliability problem except exacerbating by the stressed generation dispatch.
Appendix 3: DETAILED STUDY METHODOLOGY

Figure 8. Example of deliverability main report

Figure 9. Example of deliverability report-generation capacity reduction