NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL
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White Paper

Certification and Performance Measures for Interconnected Operations Services

Prepared by the
Interconnected Operations Services Implementation Task Force
North American Electric Reliability Council

Draft 1.0
December 15, 1999

Certification and Performance Measures for Interconnected Operations Services

Subsections

A. Introduction

This White Paper explains the certification and performance measures currently in development for Interconnected Operations Services (IOS). The IOSITF has made substantial progress in the development of methods to measure the provision of IOS. Performance measures are necessary because the formation of electricity markets in North America is increasingly requiring unbundling of essential reliability functions that were formerly produced and delivered as part of a bundled electricity product. The advent of competition in wholesale electricity markets has also resulted in the separation of transmission and generation functions, in some cases through divestiture and in other cases through functional unbundling. It is essential that unbundled reliability products such as IOS can be measured and that there are standard qualifications for the resources that provide these products.

Draft Operating Policy 10, like other NERC Policies, proposes two sets of metrics: certification criteria and performance measures. The focus of IOS metrics is on the key factors needed for reliability. These attributes must be measured as precisely and efficiently as possible. Certification tests allow the IOS SUPPLIER to demonstrate the minimum capabilities necessary to provide an IOS.

Performance measures assess the real-time delivery of a service by an IOS SUPPLIER. By design, the extent of the certification tests is inversely related to the ease of measuring real-time performance. For example, the certification test for the REGULATION is quite simple because REGULATION is delivered on a continuous basis. On the other hand, the certification test for the SYSTEM BLACK START CAPABILITY is more extensive because this service is rarely delivered, and, therefore, cannot routinely be measured. IOS that are deployed only occasionally (e.g., CONTINGENCY RESERVE) have a certification test that is more extensive than REGULATION but simpler than that for SYSTEM BLACK START CAPABILITY.

Performance measures can be monitored at the IOS SUPPLIER (i.e., aggregated) level. This allows the IOS SUPPLIER to meet performance requirements in a flexible manner while holding the IOS SUPPLIER accountable for the aggregate performance of its individual IOS RESOURCES.

The performance metrics presented in this White Paper were developed to meet three criteria:

- Support reliability objectives of the OPERATING AUTHORITY (e.g., meet Policy 1 requirements for CPS and DCS);
- Be technically justified; and
- Operate well in a variety of regulatory frameworks and market structures and conditions.

Each performance metric includes three components. The *measure* (e.g., area control error) identifies the characteristic to be measured (analogous to miles per hour for a highway speed limit). The *criteria* bound the measure (e.g., CPS1 and 2 for area control error and 65 miles per hour for a speed limit). Finally, the metric may include *conditions* under which the measurements apply (e.g., the Policy 1 DCS measure applies only after a major contingency occurs and speed limits differ between rural freeways and urban roads).

This White Paper represents extensive work to develop the IOS metrics. However, the work is not yet complete. In its present form, a general framework for IOS certification and IOS performance measurement is provided. The remaining work is to develop Compliance Templates for due process comment and ultimately approval by the NERC Board of Trustees. Since measures should support standards, the IOSITF proposes to develop the compliance metrics pursuant to approval of Operating Policy 10 – Interconnected Operations Services.

Section B of this document reviews IOS certification criteria and test methods. Section C reviews IOS performance measures.

B. IOS Certification Criteria and Test Methods

1. Regulation and Load Following

Certification tests for REGULATION and LOAD FOLLOWING are similar. The principal difference is the duration of the test and the frequency and period of signal changes.

Regulation

1. A REGULATION certification test is conducted during a continuous 60-minute period that the IOS SUPPLIER and OPERATING AUTHORITY mutually agree upon in advance.

2. The OPERATING AUTHORITY shall confirm the date and time of the test with the IOS RESOURCE using both the primary and alternate voice circuits in order to validate the voice circuits.

3. For the 60-minute duration of the test, the CONTROL AREA shall send a random sequence of raise, hold, and lower control signals to the IOS RESOURCE. Each signal shall remain unchanged for at least one minute. The string of random control signals shall not request unit performance beyond the stated high limit, low limit, and ramp rate limit agreed upon prior to the test.

4. The IOS RESOURCE'S average real power output for each clock-minute will be measured and recorded. The correlation coefficient between the expected average power from one minute to the next [limited to no more than the *Initial Value + (Request * 1/2* Stated* Ramp Rate)] and the actual measured real power output during those minutes shall be statistically significant to *two positive standard deviations* in order to pass the test.

5. Upon successful demonstration of all test criteria, the certifying authority shall certify the IOS RESOURCE is capable of providing REGULATION and shall provide a copy of the certificate to the IOS SUPPLIER.

Load Following

1. A LOAD FOLLOWING certification test is run during a continuous time period that the IOS SUPPLIER and OPERATING AUTHORITY mutually agree upon in advance.

2. The OPERATING AUTHORITY shall confirm the date and time of the test with the IOS RESOURCE using both the primary and alternate voice circuits to validate the voice circuits.

3. For the duration of the test, the CONTROL AREA shall send a random sequence of raise, hold, and lower control signals to the IOS RESOURCE. Each signal shall remain unchanged for the predetermined minimum time between load changes (e.g., five or ten minutes). The test shall consist of 15 load change requests. The string of random control signals shall not request unit performance beyond the stated high limit, low limit, and ramp rate limits agreed upon prior to the test.

4. The IOS RESOURCE'S average real power output for each minute will be measured and recorded. The correlation coefficient between the expected average power from one minute to the next [limited to no more than the *Initial value + (Request * 1/2* Stated Ramp Rate*)] and the actual

measured real power output during those minutes shall be statistically significant to *two positive standard deviations* in order to pass the test.

5. Upon successful demonstration of all test criteria, the certifying authority shall certify the IOS RESOURCE is capable of providing LOAD FOLLOWING and shall provide a copy of the certificate to the IOS SUPPLIER.

2. Contingency Reserve – Spinning and Supplemental

Certification tests for CONTINGENCY RESERVE – SPINNING and SUPPLEMENTAL may be conducted separately or as one test.

1. A test for CONTINGENCY RESERVE – SPINNING or SUPPLEMENTAL shall be performed during a continuous 8-hour window agreed upon by the IOS SUPPLIER and the OPERATING AUTHORITY.

2. The OPERATING AUTHORITY shall confirm the date and time of the test with the IOS RESOURCE using both the primary and alternate voice circuits to validate the voice circuits.

3. At any time during the eight-hour window, selected by the OPERATING AUTHORITY, and not previously disclosed to the IOS SUPPLIER, the OPERATING AUTHORITY shall send a signal to the IOS RESOURCE requesting it to provide its declared amount of CONTINGENCY RESERVE – SPINNING OR SUPPLEMENTAL.

4. The IOS RESOURCE output shall be measured as clock-minute average outputs for a) the clock-minute prior to the instructions being received from the OPERATING AUTHORITY; b) the clock-minute following receipt of instructions from the OPERATING AUTHORITY and continuing for T_{DCS} - X minutes (where T_{DCS} is the number of minutes allowed by the Policy 1 Disturbance Control Standard for recovery from a major outage and X is the previously agreed upon time that the OPERATING AUTHORITY requires to identify the need to deploy the reserves and to notify the IOS RESOURCE); c) and for each of the subsequent 19 clock-minutes. All measurements shall be between 100% to Y% of the declared amount of CONTINGENCY RESERVE, where Y is an INTERCONNECTION-specific factor.

5. Upon successful demonstration of all test criteria, the certifying authority shall certify the IOS RESOURCE is capable of providing CONTINGENCY RESERVE – SPINNING or SUPPLEMENTAL and shall provide a copy of the certificate to the IOS SUPPLIER.

Contingency Reserve Certification for IOS RESOURCES without Direct Metering

An IOS RESOURCE that does not have direct metering (i.e., meters that record output at least once every few minutes, the output of which is telemetered to the OPERATING AUTHORITY) may be certified for CONTINGENCY RESERVE, provided the IOS RESOURCE is sufficiently large that its MW output can be measured by CONTROL AREA metering. The IOS RESOURCE must still demonstrate the full capabilities outlined in the certification criteria, with the exclusion of the metering requirements. The test must be performed during periods when CONTROL AREA conditions are sufficiently stable to allow reliable measurement of the MW output of the IOS RESOURCE. The OPERATING AUTHORITY will require significant flexibility in scheduling such tests. Because the OPERATING AUTHORITY is not able to directly meter the output of these resources, it will conduct more frequent tests to certify such resources.

1. Although metering requirements may be waived for this test, the voice communications requirements remain.

2. The OPERATING AUTHORITY will have the right to conduct an unannounced test of the IOS RESOURCE any time the resource is declared available. No more than two unannounced tests will be conducted per month and no more than four per year.

3. The amount of response delivered by a non-metered IOS RESOURCE may vary with conditions such as total load, ambient temperature, season, day of the week, time of day, etc. The IOS SUPPLIER will provide to the OPERATING AUTHORITY an estimate of the amount of reserves that will be available and under what conditions and by how much this varies. Testing will then characterize and certify the non-metered resource to provide CONTINGENCY RESERVES under a range of system and resource conditions.

4. Resource response will be calculated from the response detected by the control area metering. This calculated response will be used to verify IOS RESOURCE capability in a similar manner to the metered tests described previously.

3. Reactive Power Supply from Generation Resources

1. The IOS RESOURCE shall perform the unit automatic voltage regulator (AVR) tests, and supply IOS RESOURCE AVR data as required by the NERC Planning Standards "System Modeling Data Requirements, Generation Equipment." Sections 2B, Measurement 4, and 2B, Measurement 6. The AVR tests will be performed upon initial certification, and periodically at an OPERATING AUTHORITY set time interval no more often than once every five years. The AVR tests are run at a time mutually agreed upon in advance by the IOS SUPPLIER and the OPERATING AUTHORITY.

2. The IOS RESOURCE must verify and maintain its stated reactive capacity, as required by the NERC Planning Standards "System Modeling Data Requirements, Generation Equipment." Sections 2.B, Measurement 3. This reactive capacity certification test will verify the IOS RESOURCE reactive capacity. The reactive capacity test will be performed upon initial certification, and periodically at an OPERATING AUTHORITY set time interval no more often than once every five years. The reactive capacity test is run at a time mutually agreed upon in advance by the IOS SUPPLIER and the OPERATING AUTHORITY. The test results, as described in 2.B, Measurement 3, shall be communicated to the OPERATING AUTHORITY.

3. Upon successful demonstration of all test criteria, the certifying authority shall certify the IOS RESOURCE is capable of providing REACTIVE POWER SUPPLY FROM GENERATION and shall provide a copy of the certificate to the IOS SUPPLIER.

4. Frequency Response

Because it is impractical to move INTERCONNECTION frequency for test purposes, it is necessary to use simulated frequency excursions outside the allowed deadband to perform a certification test of the IOS RESOURCE.

The FREQUENCY RESPONSE test shall be performed at a time that is mutually agreed upon by the IOS SUPPLIER and OPERATING AUTHORITY.

1. The OPERATING AUTHORITY shall confirm the date and time of the test with the IOS RESOURCE.

2. A test frequency signal will be provided to the IOS RESOURCE and the IOS RESOURCE'S response will be measured. The frequency value of the test signal will be calculated to require the full response amount (MW) being certified, based on the IOS RESOURCE'S deadband and droop characteristic. The pre-contingency output (or consumption) of the IOS RESOURCE shall be calculated as the average power recorded for the clock minute prior to the injection of the test frequency signal. After each frequency test signal is injected, the test measurements shall include the MW output (or consumption) ten seconds after the frequency change and the average for each clock-minute from ten seconds through ten minutes following each frequency change. To pass the test, the measured values must differ from the pre-contingency output (or consumption) within the bounds listed in the FREQUENCY RESPONSE criteria.

3. It may be necessary to construct alternative tests for IOS RESOURCES that cannot produce (or consume) real power while connected to a test frequency source. In this case, output (or consumption) may be calculated based upon measured performance of that portion of the system that can be tested (throttle valve position, for example). Testing requirements should be negotiated between the IOS SUPPLIER and the OPERATING AUTHORITY.

4. Upon successful demonstration of all test criteria, the certifying authority shall certify the IOS RESOURCE is capable of providing FREQUENCY RESPONSE and shall provide a copy of the certificate to the IOS SUPPLIER.

5. System Black Start Capability

SYSTEM BLACK START CAPABILITY certification testing is divided into three parts, depending on the frequency of testing required.

Basic Starting Test

The basic ability of the IOS RESOURCE to start itself, without support from the grid, is tested at least once every three years. The test is run during a one-week period mutually agreed upon in advance by the IOS SUPPLIER and OPERATING AUTHORITY. The test itself does not require one week, but may be called by the OPERATING AUTHORITY any time during the week.

1. The OPERATING AUTHORITY shall confirm the dates of the test with the IOS SUPPLIER.

2. At a time during the one-week test window, selected by the OPERATING AUTHORITY, and not previously disclosed to the IOS RESOURCE:

   2.1. The IOS RESOURCE, including all auxiliary loads, will be isolated from the power system;

   2.2. Within the agreed upon time of being directed to do so by the CONTROL AREA operator, the IOS RESOURCE will start without assistance from the system; and

   2.3. The IOS RESOURCE must remain stable (both frequency and voltage) while supplying only its own auxiliary loads or loads in the immediate area for at least 30 minutes.

Line Energizing Test

The ability of the IOS RESOURCE to energize transmission will be tested when conditions permit (during transmission maintenance, for example) but at least once every three years. Tests will be conducted at a time mutually agreed upon by the IOS SUPPLIER and the OPERATING AUTHORITY.

1. Sufficient transmission will be de-energized such that when it is picked up by the IOS RESOURCE it demonstrates the IOS RESOURCE'S ability to energize enough transmission to deliver required output to the generator or load that the restoration plan calls for this IOS RESOURCE to supply. The OPERATING AUTHORITY shall be responsible for transmission connections and operations that are compatible with the capabilities of the IOS RESOURCE.

2. Conduct a ***Basic Starting Test***.

3. The CONTROL AREA will direct the IOS RESOURCE to energize the previously de-energized transmission, while monitoring frequency and voltages at both ends of the line. Alternatively, if the OPERATING AUTHORITY agrees, the transmission line can be connected to the IOS RESOURCE before starting, allowing the resource to energize the line as it comes up to speed. This avoids the energizing surge.

4. The IOS RESOURCE must remain stable (both frequency and voltage) while supplying only its own auxiliary loads or external loads and controlling voltage at the remote end of the transmission line for at least 30 minutes.

Load Carrying Test

The ability of the IOS RESOURCE to remain stable and to control voltage and frequency while supplying restoration power to the generator or load that the restoration plan calls for this IOS RESOURCE to supply shall be tested as conditions permit, but at least once every six years.

1. Conduct a ***Basic Starting Test***.

2. Conduct a ***Line Energizing Test***.

3. The CONTROL AREA operator will direct picking up sufficient load at the remote end of the isolated transmission system to demonstrate the IOS RESOURCE'S capability to supply the required load identified in the restoration plan, while maintaining voltage and frequency for at least 30 minutes.

Certification for System Black Start Capability

1. Certification will be provided to an IOS RESOURCE that has met the following requirements:
   - 1.1. Verified control communication path performance;
   - 1.2. Verified primary and alternate voice circuits for receipt of instructions; and
   - 1.3. Passed the ***Basic Starting Test***;
   - 1.4. Passed the ***Line Energizing Test;***
   - 1.5. Passed the ***Load Carrying Test***.

2. Upon successful demonstration of SYSTEM BLACK START CAPABILITY, the certifying authority shall certify the IOS RESOURCE as being permitted to provide the IOS and shall provide a copy of the certificate to the IOS SUPPLIER. Certification shall be valid for one year from the date of the last successful Basic Starting test, three years from the date of the last successful Line Energizing

Test, or six years from the date of the last successful Load Carrying Test, whichever is earliest. Certification shall be revoked if the IOS RESOURCE fails to successfully perform during an actual restoration event, until the IOS RESOURCE is successfully retested. Retesting is only required for the aspect of SYSTEM BLACK START CAPABILITY (Basic Starting, Line Energizing, or Load Carrying) for which the IOS RESOURCE failed.

C. Real Power IOS Performance Measures

This section reviews the proposed methods for the measurement of IOS RESOURCE performance in the provision of IOS. These methods are necessary for dispatch and control and to quantify the delivery of the reliability product. As in draft Policy 10, the concepts here focus on the supply-side delivery of reliability building blocks and do not imply measurement of the delivery of ancillary services to TRANSMISSION CUSTOMERS.

1. Performance Measurement Concepts

The expected amount of five of the IOS can be conceptually represented simply as a real power output "schedule" requested by the OPERATING AUTHORITY from the IOS SUPPLIER. This "schedule" is not a typical energy schedule, but is a scheduled output of the IOS RESOURCE(S) that provides the variable response necessary to make up each IOS. The IOS "schedule" is of course subject to the agreed upon capabilities of the IOS RESOURCE(S). The appropriate IOS measurement, then is the *difference between the actual and expected (requested) output of the IOS RESOURCE(S), subject to agreed upon capabilities of the IOS RESOURCES(S)*. There are five IOS for which this concept applies in the measurement of real-time provision of the reliability product:

- REGULATION
- LOAD FOLLOWING
- FREQUENCY RESPONSE
- CONTINGENCY RESERVE-SPINNING
- CONTINGENCY RESERVE-SUPPLEMENTAL.

Because these five IOS share a common basis in measurement, they are addressed together in the next section of this White Paper. Performance measures for the remaining two IOS are treated separately in Section D:

- REACTIVE POWER SUPPLY FROM GENERATION SOURCES
- SYSTEM BLACK START CAPABILITY.

2. Real Power IOS Process Overview

The process diagram in Figure 1 below shows that IOS are typically dispatched by the OPERATING AUTHORITY and provided by an IOS SUPPLIER. Generating units, loads, and possibly other types of devices can provide IOS. Measurement methods can be used to quantify the component elements of IOS. For example, REGULATION itself cannot be measured as a single variable because REGULATION is a process. Only specific components of the REGULATION process can be measured. Each of the five reliability components detailed in Figure 1 is a candidate for measurement.

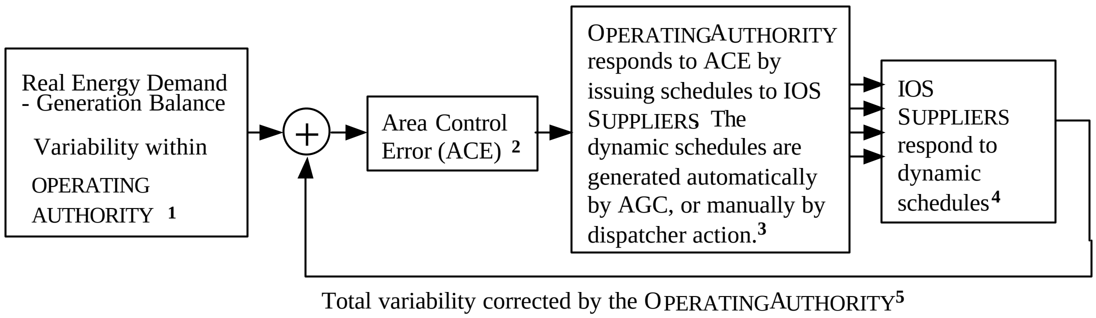


Figure 1. Real Energy Demand-Generation Balance Process Diagram.

1. The OPERATING AUTHORITY total variability is comprised of: changes in load, frequency deviation, losses, unscheduled generating unit changes, scheduled changes in generator output, interchange transaction ramps, and regulation transactions. A regulation transaction involves moving variability from one OPERATING AUTHORITY ACE into another OPERATING AUTHORITY'S ACE.

2. AREA CONTROL ERROR (ACE) represents real power that is provided to a CONTROL AREA by the rest of the INTERCONNECTION, because Interconnection-wide power balances at all times. In other words, power that is not generated by the OPERATING AUTHORITY is supplied by the INTERCONNECTION. ACE is the sum of the internal OPERATING AUTHORITY variability (1) plus the variability correction provided by the OPERATING AUTHORITY'S IOS SUPPLIERS (5). ACE magnitudes are measured, and should be limited to the CPS and DCS bounds set in Policy 1.

3. The OPERATING AUTHORITY responds to ACE magnitudes by issuing dynamic (time varying) schedules to IOS SUPPLIERS of the real-energy IOS. The Automatic Generation Control (AGC) algorithm automatically generates dynamic schedules that are sent by telemetry to REGULATION IOS SUPPLIERS. Manual or automatic dispatch actions define variable schedules that are sent to IOS SUPPLIERS of LOAD FOLLOWING and CONTINGENCY RESERVE. CONTINGENCY RESERVE is activated to recover from unusually large ACE magnitudes. INTERCONNECTION frequency directly deploys real power from IOS SUPPLIERS of FREQUENCY RESPONSE. The measurement methods described in this White Paper can be used to quantify the energy and variability associated with each of these five IOS "schedules". The maximum scheduled amount (capability) can be measured, as well as the scheduled amount actually requested within a scheduling period.

4. IOS SUPPLIERS receive, and respond to, the dynamic schedule sent from the OPERATING AUTHORITY. The difference between the IOS SUPPLIER total output and the sum of all of its "schedules" is the SUPPLIER CONTROL ERROR (SCE). The measurement methods described here can be used to quantify the energy and variability associated with the SCE.

5. The sum of all the IOS SUPPLIER outputs is the variability corrected internally by the OPERATING AUTHORITY. The measurement methods described here can be used to quantify the energy and variability associated with each IOS SUPPLIER'S actual output.

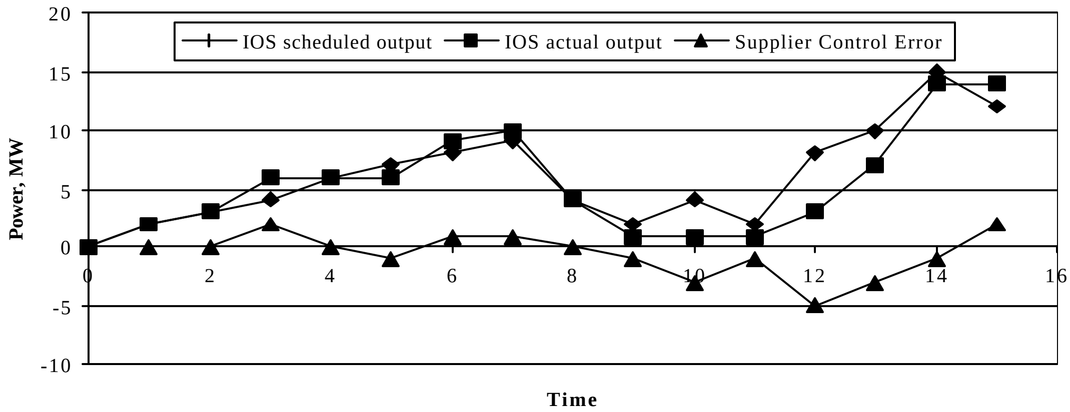


Figure 2. Simplified Example Showing IOS Scheduled Output, IOS Actual Output, and the Supplier Control Error.

3. IOS Supplier Control Error

The measurement method quantifies the energy and variability associated with the IOS scheduled output and SCE. Figure 2 presents a simplified example of the IOS SUPPLIER'S scheduled output, actual output, and the SCE. If the IOS SUPPLIER has multiple active schedules, the IOS scheduled output is the sum of all active schedules. The SCE is the difference between the IOS actual output and the IOS scheduled output. The IOS SUPPLIER delivery error is completely defined by the SCE, much as the CONTROL AREA'S error is defined by ACE. The SCE presents additional variability to the OPERATING AUTHORITY, so IOS are consumed to correct for the SCE of any IOS SUPPLIER. IOS measurement includes quantification of the energy and variability in the:

- IOS RESOURCE maximum capability,
- IOS scheduled output and
- Supplier Control Error.

The IOS SUPPLIER's actual output could also be measured, but this additional variable does not provide new information not already contained in the IOS scheduled output and SCE.

The IOS RESOURCE maximum stated capability would be agreed upon by the IOS SUPPLIER and OPERATING AUTHORITY and certified as necessary to meet certification requirements. While it is important to identify capabilities when the service is procured, capabilities may change over time. For example, unit deratings are commonly used to track temporary reductions in machine real-power capability. An equivalent method is needed to track temporary reductions in the ability to supply a particular IOS.

The IOS scheduled output is also a candidate for measurement. This measurement would indicate how much of the stated capabilities were dispatched within each measurement interval. An IOS RESOURCE providing REGULATION that is moving at its maximum ramp rate over the entire real-power range for one measurement interval is experiencing a different level of wear and tear than the same IOS RESOURCE that is only asked to ramp slowly from its minimum to maximum MW limits.

Real-energy IOS are usually dispatched within a smaller time interval than the block energy scheduling period, which is typically one hour. An IOS SUPPLIER of REGULATION may receive a new scheduled output every AGC cycle (typically two to six seconds), and CONTINGENCY RESERVE may be fully loaded within T_{DCS} and ramped out completely within a scheduling period. T_{DCS} is the Disturbance Control Standard recovery time, which used to be 15 minutes, but has been extended to 15 minutes on an interim basis. The measurement method needs to quantify the energy and variability associated with IOS schedules and SCE within each scheduling period.

The expectation for any real-energy IOS SUPPLIER is that the IOS RESOURCES follow the continually updated variable schedule. By following this schedule, the IOS SUPPLIER provides the real-energy response that allows the OPERATING AUTHORITY to meet the CPS and DCS performance standards. An IOS SUPPLIER that has multiple active schedules is expected to follow its total scheduled amount. The SCE is the difference between actual output and all active schedules. The active schedules can include a mix of energy, REGULATION, and other real-energy services. If the IOS SUPPLIER supplies services to several commercial organizations, the purchasing entities will need to agree on how this single SCE is allocated to each service.

$SCE = P_a - P_s$
where: P_a = IOS SUPPLIER actual metered power output
P_s = Sum of all schedules at each sampling interval for this IOS SUPPLIER.

4. Regulation and Load Following Capabilities

Prior to providing service, all IOS SUPPLIERS declare their REGULATION and LOAD FOLLOWING capabilities. These declared capabilities may change over time, but any change in capability must be communicated to the OPERATING AUTHORITY. At a minimum, the following information is included in the capability declaration:

- High limit (P_{max} = maximum power output (MW) available while on automatic control)
- Low limit (P_{min}= minimum power output (MW) available while on automatic control)
- Ramp up and ramp down limit (R_{max} = maximum increasing ramp rate in MW/min available while on automatic control; R_{min} = maximum decreasing ramp rate in MW/min available while on automatic control)
- Signal rate (dt = minimum time, in seconds or minutes, between two requests for output changes from the OPERATING AUTHORITY)
- Acceleration (J = the rate of change of ramp rate, MW/min^2). This term captures the “turn around time” characteristic of many IOS RESOURCES. For those IOS RESOURCES with no acceleration restriction, the maximum acceleration is naturally limited by the signal rate. This maximum acceleration would be J_{max} = (Maximum Ramp Up Rate – Maximum Ramp Down Rate)/signal rate.

The following equations (Taylor series expansions of power output and ramp rate) compute the maximum schedule that can be sent to, and expected from, an IOS RESOURCE during the next control signal change ($t_n = t_{n-1} + dt$) while respecting the IOS RESOURCE power, ramp, and acceleration limits. The schedule needs to respect the IOS RESOURCE limits or otherwise the SCE will show a delivery error even though the resource is performing at its stated capabilities.

$P_{t+1} = P_t + R_t * dt + 1/2 * J_t * dt^2$
$R_{t+1} = R_t + J_t * dt$
Subject to:

$P_{min} < P_t < P_{max}$ $R_{min} < R_t < R_{max}$ $J_{min} < J_t < J_{max}$

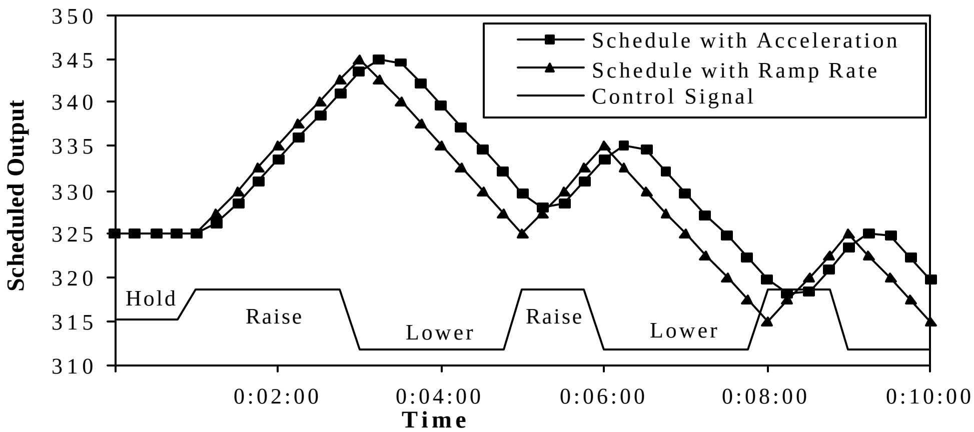


Figure 3. REGULATION Schedule with and without Acceleration Limits.

The same equations, when evaluated at the minimum (P_{min}, R_{min}, and J_{min}) limits, specify the maximum downward movement that the OPERATING AUTHORITY can request from the IOS SUPPLIER.

Figure 3 shows the resource schedules with and without the acceleration (J) term. The SCE will be larger if acceleration is not considered (i.e., if the OPERATING AUTHORITY assumes that the resource can accelerate at the maximum rate noted above), especially for units with slower acceleration (typically larger generating units).

This capability declaration information fully describes the maximum variable schedule that the IOS SUPPLIER agrees to follow. The total REGULATION capability is this maximum variable schedule. The OPERATING AUTHORITY may not ask the IOS SUPPLIER to follow a schedule that exceeds the maximum declared capabilities unless allowances have been made to discount the additional SCE caused by this increased schedule.

The variable schedule sent from the OPERATING AUTHORITY to the IOS RESOURCE should be referenced from the last *scheduled* output, and not from the last *actual* output of the IOS RESOURCE. For example, suppose that an IOS RESOURCE declared a ramp rate of 10 MW/minute, but could ramp at only 5 MW/minute. If the variable schedule follows the 10 MW/minute ramp, the SCE will grow over time as the IOS RESOURCE falls further behind the schedule. This larger SCE is appropriate since the IOS RESOURCE is not performing at its stated capabilities. The OPERATING AUTHORITY can select any output within the limits of the IOS SUPPLIER'S stated capabilities. These limits are:

$$(\text{High Limit - Low Limit}) = |Pa-Ps_{|t-1}|+2*R*dt \quad .$$

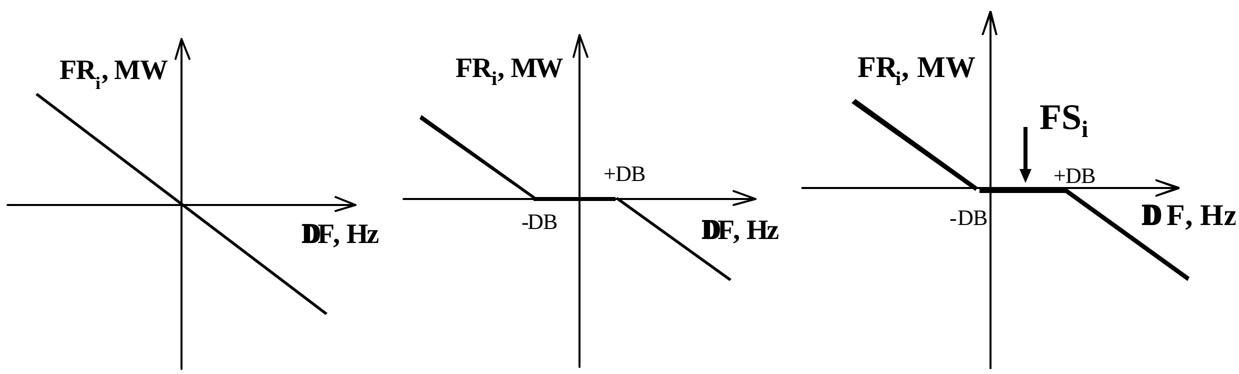
At some point, a large SCE can be reduced to zero by setting the IOS RESOURCE scheduled output equal to its actual output, provided that the IOS RESOURCE historical capabilities are reduced by an amount equivalent to the observed performance shortfall. This performance shortfall is similar to a capacity derating in that it may be temporary or may extend for a period of time.

5. Frequency Response Capabilities

Prior to providing the FREQUENCY RESPONSE service, IOS SUPPLIERS must declare their FREQUENCY RESPONSE capabilities. These declared capabilities may change over time, but any change in capability must be communicated to the OPERATING AUTHORITY. At a minimum the following information is included in the capability declaration:

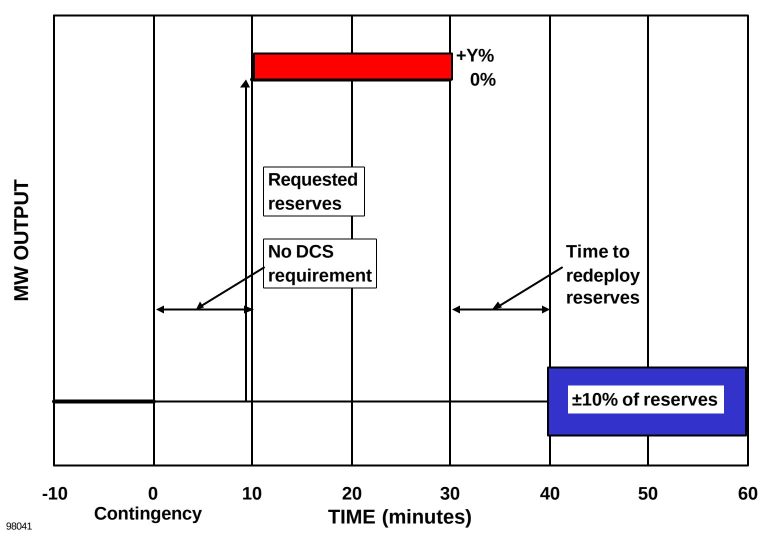
- Governor characteristics (e.g., droop and deadband) sufficient to define the expected IOS RESOURCE MW output as a function of frequency changes and time (i.e., speed of response)
- Amount of time the MW response can be maintained

These capabilities are necessary and sufficient to describe the maximum variable schedule that the IOS SUPPLIER agrees to follow. Figures 4, 5, and 6 show examples of typical frequency response relationships between expected real-power output and system frequency error. The FREQUENCY RESPONSE IOS is automatically dispatched through INTERCONNECTION frequency levels or changes. The IOS SUPPLIER'S scheduled output should be modified as a function of frequency so that the SCE does not penalize the IOS SUPPLIER when this service is actually provided.



Figures 4, 5 and 6 – FREQUENCY RESPONSE examples of expected real-power output (FR$_i$ in MW) versus frequency error (DF in Hz) which show a linear, linear with deadband, and linear with deadband and variable frequency setpoint FS$_i$ response.

6. Contingency Reserve – Spinning and Supplemental Capabilities



Prior to providing CONTINGENCY RESERVE service, all IOS SUPPLIERS must declare their capabilities for CONTINGENCY RESERVE – SPINNING and SUPPLEMENTAL. These declared capabilities may change over time, but any change in capability is communicated to the OPERATING AUTHORITY. CONTINGENCY RESERVE – SPINNING must be provided by synchronized, unloaded generation, but all other characteristics of these two IOS are the same. At a minimum, the following information is included in the capability declaration:

- Maximum amount that can be loaded within (T_{DCS} - X) minutes, where T_{DCS} is the number of minutes (e.g., ten or 15 minutes) allowed by the Policy 1 Disturbance Control Standard for recovery from a major outage and X is the amount of time from the contingency, or other large ACE change, until the OPERATING AUTHORITY dispatches the CONTINGENCY RESERVE IOS RESOURCE.
- Length of time the MW response can be maintained (minimum of an additional 20 minutes).
- Length of time needed to subsequently ramp out the MW response (usually ten minutes).
- Length of time that must elapse before the CONTINGENCY RESERVE IOS RESOURCE can be re-deployed as CONTINGENCY RESERVE.

These capabilities are necessary and sufficient to describe the maximum variable schedule that the IOS SUPPLIER agrees to follow. The total CONTINGENCY RESERVE – SPINNING and SUPPLEMENTAL capability is this maximum variable schedule. The OPERATING AUTHORITY may not require the IOS SUPPLIER to follow a schedule that exceeds the maximum declared capabilities unless allowances have been made to discount the additional SCE caused by this increased schedule.

7. Variability Measurement Methods

Measuring energy (average power over time) over a scheduling period is practical with existing metering capabilities. Because real-energy IOS schedules are modified from minute to minute, hourly averages are not sufficiently detailed to ensure the service was delivered.

For example, Figure 7 shows a very simple REGULATION schedule that ramps up for one-half hour, followed by a REGULATION schedule that ramps down for the next half hour. The IOS output is unchanged across the hour, leaving the SCE with zero average energy for the hour. The requested energy happened to be delivered in this example, but the REGULATION service was not delivered. *Intra*hour energy measurements (e.g., at one-minute intervals) are needed for the schedule and SCE. A measurement of variability is also needed to fully describe the IOS variable schedule and SCE.

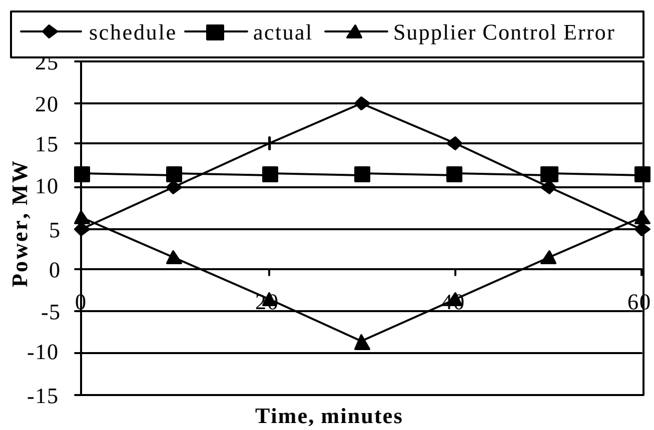


Figure 7. Example IOS schedule

Many alternative methods exist to quantify variability. The method selected for measurement of real-power IOS performance measurement is to use statistics to calculate variability summaries.

Statistical calculation methods are commonly used to summarize selected characteristics of a large quantity of data. Statistical calculation techniques that reduce variability to a single number within each scheduling period include, but are not limited to:

- Covariance
- Standard deviation
- Range (max – min)
- Path (arc) length, the total distance traveled within a scheduling period

The Interconnected Operations Services Implementation Task Force (IOSITF) has chosen to use covariance, although other methods could be possible. The choice of covariance would help ensure comparability and consistency between IOS and Policy 1 CPS and Policy 10 performance measures.

8. Real Power IOS Performance Criteria

The OPERATING AUTHORITY is required to comply with the Policy 1 DCS to correct large ACE magnitudes. DCS places large penalties on the OPERATING AUTHORITY if ACE is not restored to zero or its pre-disturbance value within the prescribed T_{DCS} minutes.

Contingency Reserve Performance Criteria

The performance criteria for CONTINGENCY RESERVE requires that the SCE shall be greater than 0% and less than +Y% of the deployed MW amount during disturbance recovery. The value for Y shall be determined by the IOSITF for each INTERCONNECTION based on its bias, largest resource, and number of NERC reportable events. This criterion shall be met for the full duration of CONTINGENCY RESERVE – SPINNING and SUPPLEMENTAL deployment.

FREQUENCY RESPONSE Performance Criteria

The SCE for the FREQUENCY RESPONSE service shall be greater than 0% of the requested MW amount during disturbance recovery.

Regulation Performance Criteria

For the REGULATION IOS, the OPERATING AUTHORITY can choose from among various methods for limiting the SCE. One method requires the long-term standard deviation of the SCE to be less than a specific value. The following equation mathematically represents the proposed criterion. This inequality must be met for 90% of the periods in a month to achieve acceptable performance.

$[\mathrm{StDev}\{|SCE_{sampled}|\}_{hour}] \leq \mathbf{s}_{limit}$

Where: $SCE_{sampled}$ = Supplier Control Error at the sampled rate (e.g., every minute).

The OPERATING AUTHORITY would select the numerical value of the limit.

A second (more complicated, but technically preferred) method requires the long-term product of SCE and ACE (or the product of SCE and frequency deviation) to be less than a specific value. This approach recognizes the covariance of SCE with ACE (or frequency deviation). Because the REGULATION service is to aid in the balance of generation and demand by reducing CONTROL AREA ACE, the SCE should be valued differently if it helps to reduce ACE or frequency errors. This criterion rewards over-performance with respect to ACE or frequency. To bound the measure, this criterion also limits the absolute value of the SCE, regardless of CONTROL AREA ACE or INTERCONNECTION frequency. These two limiting (minimum performance) criteria are intended to track the structure and intent of the Policy 1 CPS 1 and CPS2 requirements. The first measure deals with the long-term average of the product of SCE and ACE (or frequency error) and the second measure deals with the ten-minute average of SCE:

$\mathrm{Avg}[ACE_1 * SCE_1]_{hour} < SCEACE_{limit}$, and

$\mathrm{Avg}\{|SCE_1|\}_{hour} \leq SCE_{limit}$

Where: SCE_1 = one-clock minute average of the SCE.

Additional performance criteria have been considered for the REGULATION IOS, and may be found to have merit in the future. For example, require the long-term absolute mean of the SCE to be less than a specific fraction of the absolute mean of the variation in the schedule. The following equation represents the proposed criterion. This inequality must be met for 90% of the periods in a month in order to achieve acceptable performance.

$$[Avg\{|SCE_1|\}_{hour}]/[Avg\{|(P_1 - avg(P)_{hour})|\}_{hour}] \leq 0.75$$

Where: P_1 = one-clock minute average of the variable schedule
Avg(P) = Period average of the variable schedule

D. Other IOS Performance Measures

1. Reactive Power Supply from Generation Sources Performance Criteria

Prior to providing the REACTIVE POWER SUPPLY FROM GENERATION SOURCES, all IOS SUPPLIERS must declare their reactive capabilities. These declared capabilities may change over time, but any change in capability must be communicated to the OPERATING AUTHORITY. At a minimum the following information is included in the capability declaration:

- Unit automatic voltage regulator characteristics sufficient to define the expected IOS RESOURCE reactive power output as a function of voltage changes. Reactive capabilities are typically expressed graphically as the reactive output, both maximum and minimum, versus the IOS RESOURCE real-power output. Several families of curves could be defined to represent stator cooling capabilities.
- Maximum and minimum reactive power (MVAR) output capabilities and speed of response.

These capabilities are necessary and sufficient to describe the maximum variable schedule that the IOS SUPPLIER agrees to follow. REACTIVE POWER SUPPLY FROM GENERATION SOURCES is automatically dispatched through system voltage changes, or by a change in the desired voltage or reactive output. The performance criteria for the OPERATING AUTHORITY and IOS SUPPLIER are shown below.

- Performance Criteria – OPERATING AUTHORITY
  - Continuous measurement of reactive power output of IOS RESOURCE(S) and periodic testing of unit(s) reactive capability.
  - Continuous measurement of transmission system scheduled voltages at points of integration with IOS SUPPLIERS and periodic testing of unit(s) voltage control capability. Upon change of voltage schedule, performance will be determined by measuring the transmission bus voltage and the unit(s) reactive power output within two minutes of the request or by telemetry to the IOS SUPPLIER.
  - Reactive reserves shall be maintained at each IOS RESOURCE sufficient to respond to evaluated contingencies without violating specified limits and burdening neighbors beyond jointly established criteria.
  - Voltage, reactive output, and AVR statuses are electronically monitored by the OPERATING AUTHORITY.
  - Meets applicable NERC Planning Standards.
- Performance Criteria – IOS RESOURCE
  - IOS RESOURCE accepts and confirms scheduled voltage or scheduled reactive output requests from the OPERATING AUTHORITY within two minutes.
  - A unit regulating to the scheduled voltage must modify MVAR output to keep the voltage error less than an OPERATING AUTHORITY specified band around the scheduled voltage. Or a unit regulating to the scheduled reactive output must modify MVAR output to keep the reactive output error less than an OPERATING AUTHORITY specified band around the scheduled reactive output. The IOS SUPPLIER must meet either the voltage or reactive-output requirements, but not both at the same time.

2. System Black Start Capability Performance Criteria

Prior to providing the SYSTEM BLACK START CAPABILITY service, IOS SUPPLIERS must declare their black start capabilities. These declared capabilities may change over time, but any change in capability must be communicated to the OPERATING AUTHORITY. At a minimum, the following information is included in the capability declaration:

- Capability to start a self-starting unit within a specified time, from an initial dead station and auxiliary bus condition;
- Maximum and minimum reactive power output capabilities;
- Capability of picking up external load within a specified time;
- Capability of running the SYSTEM BLACK START CAPABILITY unit at stated MW capacity for a specified time from when the unit is started;
- Frequency responsive capability to sustain scheduled frequency and remain stable during load pickup coordinated by the OPERATING AUTHORITY in accordance with the restoration plan; and
- Reactive supply and voltage control capability to maintain system voltage within emergency voltage limits over a range from no external load to full external load.

These capabilities are necessary and sufficient to describe the black start IOS RESOURCE capabilities. Since BLACK START IOS RESOURCES are utilized infrequently, ongoing measurement methods are not proposed. Instead, the measurement methods are proposed as surveys to be completed after resource deployment. The following are the performance criteria for the OPERATING AUTHORITY and IOS SUPPLIER.

- Performance Criteria – OPERATING AUTHORITY
  - Restoration plan includes provision of SYSTEM BLACK START CAPABILITY.
  - Tests and/or simulations were conducted according to plan. Tests provide assurance capabilities are available in the event of a blackout. These capabilities include SYSTEM BLACK START CAPABILITY resources as well as transmission and system-control capabilities.
  - Restoration drills and training include personnel from SYSTEM BLACK START CAPABILITY resources.
  - Performance of each SYSTEM BLACK START CAPABILITY resource is recorded and verified to be acceptable in the event a system blackout occurs.
- Performance Criteria – IOS RESOURCE
  - Unit starts without external power source within the OPERATING AUTHORITY specified time.
  - Unit operates at specified capacity for required time.
  - Plant auxiliaries are re-energized using the SYSTEM BLACK START CAPABILITY unit as the only source.
  - Governor responds to frequency injections in the proper direction and magnitude.
  - Unit operates continuously at stated output and duration.
  - Successful completion of training and restoration drills is recorded.
  - Frequency meter indicates frequency within stated tolerances.