Transmission Interconnection Technical Requirements for Inverter-Based Generation

Effective: January 1, 2022
Overview:

Every generator interconnecting to the transmission system must adhere to all applicable Federal and State jurisdictional requirements including but not limited to the NERC Reliability Standards governed by the North American Electric Reliability Corporation, and the Open Access Transmission Tariff (OATT) ([http://www.oatioasis.com/SOCO/SOCOdocs/Southern-OATT_current.pdf](http://www.oatioasis.com/SOCO/SOCOdocs/Southern-OATT_current.pdf)) filed with the Federal Energy Regulatory Commission (FERC). This document is intended to assist generation developer by increasing awareness of relevant requirements for inverter-based generation to achieve reliable and operationally-efficient interconnection configurations. Nothing in this document is intended to supersede provisions in the OATT, current or future NERC Standards, or other regulatory requirements.

All inverter-based generation connected to Southern Companies’ transmission system (Point of Interconnection (POI) > 40 kV) shall comply with the requirements contained in this document, which may change over time.

Generator interconnection studies will determine the required interconnection facilities and transmission system upgrades, evaluate whether the generation developer’s initial generating facility design and equipment can comply with these requirements, and may prescribe additional requirements for specific sites/interconnections. The Generating Facility’s final design and equipment will be further reviewed, and its performance evaluated during the Trial Operation period, prior to the approval for Commercial Operation. The generator owner/operator is expected to continue to comply with these requirements as a condition of interconnection with Southern Companies’ transmission system.

Unless otherwise defined herein, all capitalized terms within this document shall be defined as per the LGIP and SGIP in Southern Companies’ OATT.
### Table of Contents:

**Design and Technical Requirements for an Inverter-Based Generator Interconnection**

I. **Transmission System Protection and Coordination** ................................................. 4
   1. Main Generator Step-Up (GSU) Winding Configuration ........................................ 4
   2. Anti-islanding Requirements ................................................................................. 7
   3. Protective Devices ................................................................................................. 7

II. **Power Quality** ...................................................................................................... 9
    1. Transformer Energization Studies ......................................................................... 9

III. **Insulation and Insulation Coordination** .............................................................. 10

IV. **Voltage, Reactive Power and Power Factor Control** ........................................ 10
    1. Reactive Power/Power Factor Design Criteria ...................................................... 10
    2. Voltage Schedule Operating Requirements ........................................................ 10
    3. Voltage Deviation ................................................................................................. 10

V. **Generator Performance** ....................................................................................... 11
    1. Frequency Response / Regulation ......................................................................... 11
    2. Voltage Ride Through ........................................................................................... 12
    3. Frequency Ride Through ....................................................................................... 13
    4. Active Power/Reactive Power Priority Control Settings (P/Q-Priority) .................. 14
    5. Voltage Control Stability ..................................................................................... 15

VI. **Metering and Telecommunications** .................................................................. 16

VII. **Radio Frequency Interference** .......................................................................... 17

VIII. **Curtailment and Dispatchability Requirements** ............................................. 17
I. Transmission System Protection and Coordination

1. Main Generator Step-Up (GSU) Winding Configuration

In general, the following criteria shall be used to determine the winding configuration of the main step-up transformer connecting the inverter-based generator to the transmission system. Any deviation from this criterion must be agreed to by the Transmission Owner.

i. If the generator is requesting to connect to existing < 100 kV transmission via a dedicated line or feeder (no load on line or feeder), the high side (utility side) of the main step-up transformer’s winding configuration shall be one of the following:
   a. Delta configuration (preferred)
   b. Y-grounded configuration (with delta on the generator side)

An example is shown in Figure 2.

ii. If the generator is requesting to connect to a ≤ 230 kV radial facility, and the Transmission Owner has determined a tap configuration is appropriate, the high side (utility side) of the main step-up transformer shall be connected in Delta configuration.

An example is shown in Figure 3.

iii. If the generator is requesting to connect to a > 100 kV network facility, and the Transmission Owner has determined a tap configuration is appropriate, the high side (utility side) of the main step-up transformer’s winding configuration shall be one of the following:
   a. Delta configuration (preferred)
   b. Y-grounded configuration (with delta on the generator side)

An example is shown in Figure 4.

iv. If the generator is requesting to connect to > 100 kV network facility, and the Transmission Owner has determined a ring or straight bus configuration is appropriate, the main step-up transformer’s winding configuration shall be one of the following:
   a. Y-grounded on high side (utility side) and Delta on the low side.
   b. Y-grounded on high side (utility side) and low side with buried delta tertiary winding.

An example is shown in Figure 5.
Figure 2. Example of Main GSU Criteria 1.

Figure 3. Example of Main GSU Criteria 2.
Figure 4. Example of Main GSU Criteria 3.

Figure 5. Example of Main GSU Criteria 4.
2. **Anti-islanding Requirements**

The interconnection configuration shall not allow the generator to island with other customer load. Operating company considerations include:

i. Potential for adding load taps on the existing line. If additional load taps are planned, anti-islanding protection will be considered.

ii. Load-to-generation ratio to assess risk of islanding. For inverter-based generation:
   a. If the minimum load to total generation (sum of existing, if any, and proposed) ratio is less than 2, anti-islanding protection will be required.
      i. Solar: Minimum load during day time is considered for solar generation.
      ii. If historical load data is not available, 15% of peak non-industrial load may be used for evaluation.
   b. For interconnections where anti-islanding protection is required, the individual inverter anti-islanding protection will not be sufficient. Appropriate anti-islanding protection will be installed on the transmission system in order to disconnect the generator in a potential islanding scenario. This typically involves pilot relaying on the transmission system via fiber or power line carrier.

iii. Generators may not be allowed to operate when the system is placed in an abnormal configuration (such as for unplanned outages, maintenance, construction, etc.) and it is determined that the existing protection may not be sufficient to prevent a potential islanding condition in such configuration.

iv. Generators connected to lines operated radially will be studied for the normal expected configuration only. Generators may not be able operate when the system is placed in an abnormal configuration.

3. **Protective Devices**

Various protective devices are required to permit the safe and reliable operation of the interconnection. During the interconnection studies, the Company will determine the necessary protection requirements (type, equipment, and settings) for both the interconnection with the Generating Facility, and for the Company’s transmission system. The Generator’s interconnection protective equipment and settings must be reviewed and accepted by the Company prior to the Interconnection In-Service Date.

i. **Relays** - Protective relays are required to promptly sense abnormal system conditions and initiate the isolation of the problem area. Protective relays can generally be categorized into two major groups: industrial grade and utility grade. Utility grade relays have a higher degree of reliability and accuracy and are required in all cases. All relay settings for the inter-tie protection must be reviewed and approved by the appropriate Protection and Control department before implementation.
ii. **Instrument Transformers** - Instrument transformers that are used to provide quantities representative of the high-voltage power system to the relays are a critical part of the protection package. These current transformers (CT’s) and voltage transformers (VT’s) are available with different current and voltage ratings and accuracy class ratings. It is important that any current transformers involved in protective schemes are rated as relaying accuracy class devices. Revenue metering CT’s are not suitable for protective relaying applications.

iii. **Circuit Breakers** - The Interconnection study will determine the sufficient inter-tie minimum circuit breaker rating. Upgrading or replacing existing circuit breakers within or outside the area of the interconnection may be required due to the increased fault current levels. Circuit breakers owned by the Company are dedicated to utility protection and operation purposes and will not be used for the synchronization of the generator.

iv. **Communication Channel** - In most cases, the tie-line between the interconnecting station and the generator site is very short. A communication channel between the two sites may be necessary for high speed protection. The communication channel is required in cases where it is necessary to remotely send a signal to remove the generator from the transmission system due to a fault or other abnormal conditions that cannot be sensed by the protective devices at the generator location. Another possible need for a communications channel is for monitoring or control purposes. The communication channel is typically fiber optic cable, but could also be based on power line carrier, radio, or other means. In some cases, redundant communication channels are also required. The Generator is responsible for installing the appropriate communication channels between the generating facility and the Company’s interconnecting substation for both protection coordination and data exchange.
II. Power Quality

All inverter-based generation shall comply with the Southern Company Power Quality Policy or limits specified by the Company, which can be found in the Generator Interconnection folder on the Home page of Southern Companies’ OASIS website (www.oatioasis.com/SOCO).

Note that a permanent power quality monitoring device will be installed by the Company at the POI to monitor that inverter-based generation performs in adherence with the Southern Company Power Quality Policy.

Furthermore, during the interconnection studies, harmonic planning studies may be performed to:

1. Determine the impact of inverter-based generation produced harmonic components on electrically-close synchronous generators to ensure that the levels are within the specified machine ratings (i.e., permissible continuous equivalent negative-sequence current capability).
2. Determine if mitigation measures will be necessary to meet the machine ratings. Note that this analysis could result in stricter harmonic current injection limits than those specified in the Southern Company Power Quality Policy. In addition, harmonic planning studies may be conducted to determine the potential impact of inverter-based generation injected harmonics on existing Southern Companies’ harmonic filter banks (i.e., impact of harmonics on individual filter component ratings). Three-phase analysis may also be performed when necessary.

1. Transformer Energization Studies

Whenever a power transformer is energized, a large transient current (referred to as transformer inrush) is generated. The magnitude of the inrush current depends upon many factors such as the transformer rating, point-on-wave at time of energization, residual flux in the core, etc. The primary effects of inrush currents on the transmission system include: power quality (RMS voltage drops and temporary over-voltages due to harmonics), and protection system mis-operation. To mitigate transformer inrush effects, power transformers are generally energized from the high-side using switching devices equipped with closing resistors or controlled point-on-wave voltage closing.

Therefore, during the interconnection studies, transformer energization studies will be performed to determine the RMS voltage drop at the POI (source bus). The resultant RMS voltage will be compared against the Rapid Voltage Change (RVC) limits set forth in the Southern Company Power Quality Policy.
III. Insulation and Insulation Coordination

The objective of insulation coordination is to coordinate equipment insulation levels and protective device ratings.

It is the responsibility of the interconnecting facility to ensure that the Southern Company substation equipment is protected against lightning and switching-induced surges that originate in the interconnection facility through insulation design and protection that meets the latest IEEE C62 standards.

Basic Lightning Impulse Insulation Level (BIL) for individual station equipment shall meet or exceed Southern Company’s standard ratings listed in Table 1. Also, preferred surge arrester ratings for different system voltage levels have been provided.

<table>
<thead>
<tr>
<th>Nominal kV (Line-Line)</th>
<th>Station BIL (kV)</th>
<th>Transformer Winding BIL (kV)</th>
<th>Arrester Ratings MCOV (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>250</td>
<td>250</td>
<td>31.5</td>
</tr>
<tr>
<td>69</td>
<td>350</td>
<td>350</td>
<td>42</td>
</tr>
<tr>
<td>115</td>
<td>550</td>
<td>450</td>
<td>76</td>
</tr>
<tr>
<td>161</td>
<td>750</td>
<td>230</td>
<td>115</td>
</tr>
<tr>
<td>230</td>
<td>900</td>
<td>750</td>
<td>152</td>
</tr>
<tr>
<td>500</td>
<td>1800</td>
<td>Use Nameplate BSL</td>
<td>318</td>
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</tbody>
</table>

IV. Voltage, Reactive Power and Power Factor Control

1. Reactive Power/Power Factor Design Criteria

The Reactive Power Requirements for Generating Facilities Interconnecting to the Southern Companies’ Transmission System document can be found in the Generator Operating Requirements folder on the Home page of Southern Companies’ OASIS website (www.oatioasis.com/SOCO).

2. Voltage Schedule Operating Requirements

All Generators must comply with the Voltage Schedule Procedures posted in the Generator Operating Requirements folder on the Home page of Southern Companies’ OASIS website (www.oatioasis.com/SOCO).

3. Voltage Deviation

In general, for inverter-based generation interconnecting to the transmission system at an operating voltage between 40 kV and 100 kV, a criterion of 2.5% maximum voltage deviation at the POI is used.
V. Generator Performance

All inverter-based generation connected to Southern Companies’ transmission system (POI > 40kV) shall comply with the following requirements related to frequency response/regulation and frequency and voltage ride-through.

1. Frequency Response / Regulation

Frequency response and frequency regulation are necessary to maintain nominal frequency whenever system load and generation imbalances occur. Inverter-based generators shall have the capability to provide primary frequency response during frequency events, if operating in a condition that would allow for them to respond. The overall response of the plant shall meet the following performance aspects:

**Droop**: Droop is defined as the ratio of per unit change in frequency to per unit change in active power output. The active power-frequency control system shall have an adjustable proportional droop characteristic with a default value of 5%. The droop response should include the capability to respond in both the upward (under frequency) and downward (over frequency) directions. Transmission Provider may request a more responsive droop setting.

**Deadband**: The active power-frequency control system should have a deadband that is adjustable with a default value not to exceed ± 36 mHz.

The primary frequency response control functions shall be enabled at all times, and shall not be blocked or disabled, except under system conditions which require reactive power prioritization to support system voltage outlined in Section IV, without the express written permission of the Transmission Provider.
2. Voltage Ride Through

All inverter-based generation shall remain connected to the system and operating at normal expected output\(^1\) during and following transmission system faults including three phase faults with a clearing time not exceeding 9 cycles. The voltage ride-through requirements shall be met at the point of interconnection, and are listed in Table \(2\)\(^2\) and depicted in Figure 6. It should be noted that the curves depicted in Figure 6 apply to all voltage excursions regardless of the type of initiating event. Voltage trip settings shall be set as wide as practical while ensuring equipment protection and personnel safety to support grid reliability. This aligns with the concept that the region outside of the “No Trip Zone” is interpreted as the “May Trip Zone” and not the “Must Trip Zone”. Fundamental frequency component of the voltage shall be used when comparing to the RMS voltage ride-through curve.

**Table 2. Voltage Ride-Through Requirements.**

<table>
<thead>
<tr>
<th>Voltage (p.u.)</th>
<th>Time (sec)</th>
<th>Voltage (p.u.)</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\geq 1.2)</td>
<td>Instantaneous Trip Allowed</td>
<td>(&lt; 0.45)</td>
<td>0.15</td>
</tr>
<tr>
<td>(\geq 1.175)</td>
<td>0.20</td>
<td>(&lt; 0.65)</td>
<td>0.30</td>
</tr>
<tr>
<td>(\geq 1.15)</td>
<td>0.50</td>
<td>(&lt; 0.75)</td>
<td>2.00</td>
</tr>
<tr>
<td>(\geq 1.1)</td>
<td>1.00</td>
<td>(&lt; 0.90)</td>
<td>3.00</td>
</tr>
</tbody>
</table>

**Figure 6. Voltage Ride-Through Requirements.**

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\(^1\) For the purposes of this requirement, “operating at normal expected output” means the generation shall not momentarily cease to operate within the No Trip Zone.

3. Frequency Ride Through

All inverter-based generation shall remain connected to the system and operating at normal expected output\(^3\) during frequency excursions as described in Table 3\(^4,5\) and depicted in Figure 7. Frequency trip settings shall be set as wide as practical while ensuring equipment protection and personnel safety to support grid reliability. This aligns with the concept that the region outside of the “No Trip Zone” is interpreted as the “May Trip Zone” and not the “Must Trip Zone”.

Table 3. Frequency Ride-Through Requirements.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Time (sec)</th>
<th>Frequency (Hz)</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\geq 61.8)</td>
<td>2</td>
<td>(\leq 57.8)</td>
<td>5</td>
</tr>
<tr>
<td>(\geq 60.5)</td>
<td>(10^{(0.935\times f-1.45713)})</td>
<td>(\leq 59.5)</td>
<td>(10^{(1.7373\times f-100.116)})</td>
</tr>
<tr>
<td>(&lt; 60.5)</td>
<td>Continuous Operation</td>
<td>(&gt; 59.5)</td>
<td>Continuous Operation</td>
</tr>
</tbody>
</table>

Figure 7. Frequency Ride-Through Requirements.

\(^3\) For the purposes of this requirement, “operating at normal expected output” means the generation shall not momentarily cease to operate within the No Trip Zone.


4. Active Power/Reactive Power Priority Control Settings (P/Q-Priority)

Inverters shall have the capability to provide voltage support to the grid by prioritizing Mvar output over MW output during voltage excursion events. The inverter must operate in the Q-Priority mode (i.e., this control function must be enabled at the inverters). Q-Priority is a feature for inverters to optimize the available MVA rating to produce more reactive power during abnormal, low-voltage conditions. For instance, with the Q-Priority feature enabled, the inverter control system activates reactive current injection logic when the voltage dips below a pre-determined set-point ($V_{dip}$). Additionally, when the reactive current injection logic is activated due to system voltage dipping below the pre-determined setpoint ($V_{dip}$), the inverter control system is required to inject reactive current at a rate that is directly proportional to the decrease in voltage measured at the inverter terminal, and to produce full reactive current when the alternating current (AC) voltage at the inverter terminals drops to a level of 0.50 per unit. Once the voltage has recovered (> $V_{dip}$), the inverter shall return to the steady-state operating mode in no greater than 1 second. This equates to a minimum real power ramp rate of 100%/second. Figures 8 shows an example of correct settings resulting in acceptable performance for Q-priority, reactive current injection, and real power ramp rate. Figure 9 gives an example of the incorrect settings resulting in unacceptable performance for Q-priority, reactive current injection, and real power ramp rate.

![Graph]

**Figure 8.** Example of correct settings resulting in acceptable performance for Q-priority, reactive current injection, and real power ramp rate following voltage recovery.
Figure 9. Example of incorrect settings resulting in unacceptable performance for Q-priority, reactive current injection, real power ramp rate following voltage recovery.

5. Voltage Control Stability

The Generator Owner must design its facility to reliably operate for the minimum Short-Circuit Ratio (SCR) of 2.0. The SCR is calculated by dividing the three-phase short circuit MVA capacity at the Point of Interconnection by the maximum rated MW output of the facility under a variety of normal and contingency operating conditions. However, when there are multiple inverter-based resources located electrically close to each other, the Weighted Short Circuit Ratio (WSCR) is used. WSCR is defined as:

\[ WSCR = \frac{\sum_{i}^{N} S_{SCMVA_i} \cdot P_{RMW_i}}{\left(\sum_{i}^{N} P_{RMW_i}\right)^2} \]

Where \( S_{SCMVA_i} \) is the short circuit capacity at bus \( i \) and without the contribution from the interconnecting facility \( i \) and \( P_{RMW_i} \) is the MW rating of the interconnecting facility \( i \).

If the study identifies a SCR of less than 2.0, then either delivery limits or transmission capital projects designed to maintain minimum system strength will be identified.

Relative system strength conditions will change over time. While the interconnection study will include factors such as local area generating resources and a local transmission line outage as part of the analysis, these studies cannot anticipate all possible future system conditions.

VI. Metering and Telecommunications

The Company will install and verify metering equipment at the Point of Interconnection prior to any operation of the generating facility, and shall own, operate, test and maintain such metering equipment. Power flows to and from the generating facility shall be measured at the Point of Interconnection. The Company will provide metering quantities to the generating facility via a Generator-provided communication circuit (typically fiber from the generating facility to the interconnecting substation).

The Generator Owner shall be responsible for contacting and coordinating with the appropriate electric service provider (which may or may not be a Southern Company Operating Company) to arrange for retail station service. The Point of Interconnection metering equipment does not include the generating facility’s retail station service metering equipment unless approved as such by the Company.
VII. Radio Frequency Interference

The Interconnection Customer shall operate all equipment capable of generating radio frequency energy in compliance with, and in no event allowing its equipment to cause harmful interference as prohibited by, Section 15.5 of the FCC Rules. The Transmission Provider and the Interconnection Customer will reasonably cooperate to identify the source of any allegedly harmful interference; however, the Interconnection Customer shall be solely responsible for promptly eliminating any harmful interference caused by the Interconnection Customer’s equipment. Failure to comply with this provision may result in immediate disconnection; reconnection cannot occur until the Interconnection Customer proves, to the Transmission Provider’s reasonable satisfaction, that the interference caused by the Interconnection Customer’s equipment is corrected.

VIII. Curtailment and Dispatchability Requirements

To ensure safe and reliable operations of Southern Companies’ transmission system, Southern Company Transmission may at times require generation resource(s) to curtail its active MW generation or limit the ramping capability (up/down) as necessary. The inverter-based generating facility shall be capable of accepting and responding to, within a specified amount of time, dispatch setpoints sent in real time via supervisory control and data acquisition (SCADA) system. The facility shall also maintain and continuously provide the data points as posted in the Southern Companies’ Typical Data and Application Requirements for SOCO BA Generators. The active power ramp rate of the facility shall increase or decrease in a controlled manner as established by the Southern BA with a maximum ramp rate of up to 100% facility capacity per minute, not exceeding 100 MW/minute.

The Generation remote terminal unit (RTU) at the facility shall be configured to interface with the Southern Company’s SCADA system to send and receive data points via a dedicated communication path. In the event of loss of real time data telemetry capability, the facility shall promptly notify Southern Company and make reasonable efforts to identify and correct the issue.

The inverter-based generating facility shall successfully demonstrate dispatch and ramping response during the performance validation period. Furthermore, the facility shall demonstrate successful dispatch and ramping response during periodic testing and validation conducted by Southern Company.

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1 Inverter-Based Resource Performance Guideline - 2018-08-16 - To Pubs (nerc.com)
Page 17
<table>
<thead>
<tr>
<th>Revision</th>
<th>Effective Date</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>09/19/2016</td>
<td>Initial document created</td>
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<tr>
<td>1</td>
<td>06/25/2018</td>
<td>Added Section II and renumbered remaining Sections accordingly; modified Sections III.2 and III.5; general document cleanup</td>
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<tr>
<td>2</td>
<td>12/26/2018</td>
<td>Revised Section II. 3. Interconnections to Transmission Lines Connected to Nuclear Generating Plants</td>
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<tr>
<td>3</td>
<td>08/05/2019</td>
<td>Removed Original Sections I, II, and IV now included in Business Practices for Generator Interconnections. Revised Table 1, Table 3. Added Figure 8 and Figure 9. Revised Section 5.v Voltage Control Stability. Added Section 7.</td>
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<tr>
<td>4</td>
<td>02/21/2020</td>
<td>Added additional requirement describing the required reactive current injection response to voltage dips in section V.4.</td>
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<tr>
<td>5</td>
<td>01/01/2022</td>
<td>Added requirements describing the curtailment requirements in Section VIII.</td>
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