Advanced Power Flow Controllers

Grid Enhancing Technologies: Technical Reference Guide

2024

For Public Use

Purpose

PJM supports the transparent, cost-effective, efficient and reliable deployment of Grid Enhancing Technologies (GETs) and Alternative Transmission Technologies (ATTs) on the PJM system consistent with requirements of PJM's governing documents and manuals. PJM seeks to raise awareness of GETs applications and benefits without overstating their ability to supplant necessary transmission investment. However, the details within this guide may not be perfectly applicable to every project proposal, subset of the technology, transmission zone, or local and state regulations. Rather, the guide seeks to provide a broader understanding for the technology's background, technical and modeling considerations, potential benefits and barriers, as well as regulatory context.

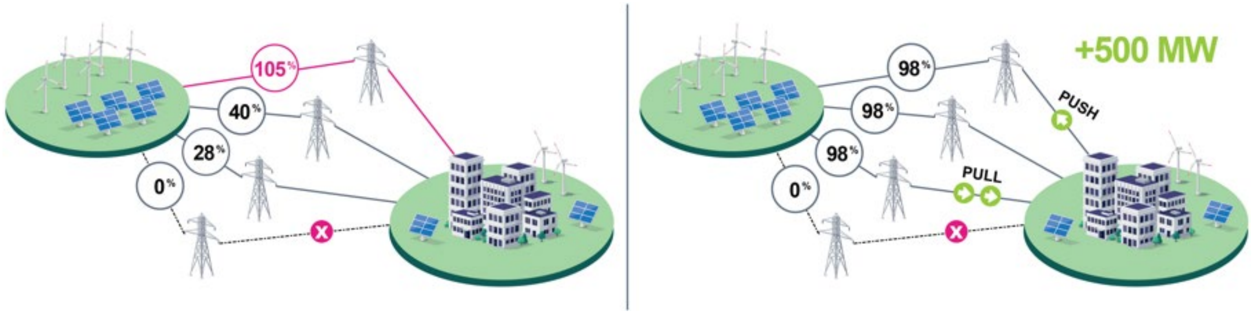
This technical reference guide is intended to aid the evaluation of Advanced Power Flow Control (APFC) devices in the region PJM serves. APFC devices are power electronics-based devices that can control power flows on transmission and distribution systems by altering the reactance of power lines. These devices have the potential to dynamically manage power flows, improve voltage stability and enhance transient stability.

PJM cannot prescribe the use of AFPC devices, but provides criteria to consider when evaluating such technology in collaboration with an impacted Transmission Owner (TO) that may own the APFC device.

Background

APFC technology injects voltage into a transmission line to produce capacitive or inductive reactance, as illustrated in Figure 1, enabling the increase or decrease of power flows on specific circuits. Potential use cases include improving the utilization of the existing transmission system while avoiding or temporarily deferring transmission upgrades.

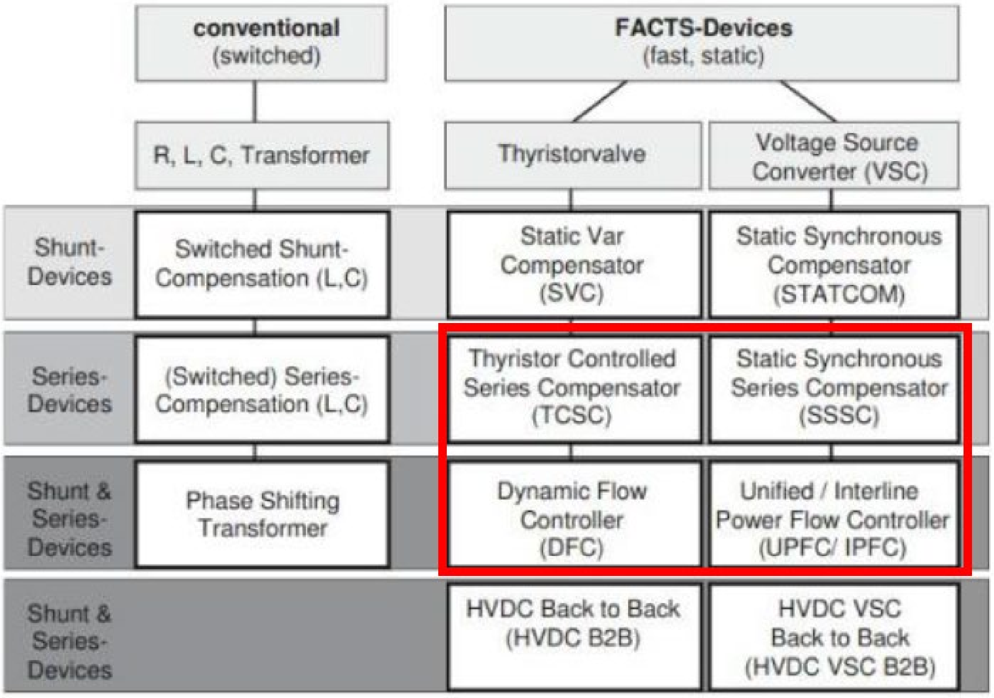
Figure 1. Visual Concept of APFC Devices



Power flow control technology is not new to the electric utility industry, and TOs in the PJM footprint utilize various Flexible Alternating Current Transmission System (FACTS) devices today, shown in Figure 2. FACTS devices are focused around the following Series Compensation Devices:

- Static Synchronous Series Compensator (SSSC), which operates like a controllable series capacitor and series inductor
- Thyristor-Controlled Series Capacitor (TCSC), which is used to increase the transmission line capability by installing a series capacitor that reduces the net series impedance thus allowing additional power to be transferred
- Unified Power Flow Controller (UPFC), which performs real-time control over power flow in transmission lines by adjusting the line parameters, including node voltages, phase angle and line impedance, which cover all adjustable parameters of other FACTS

Figure 2. FACTs Device Classifications



X-P Zhang, C Rehtanz, and B Pal, "Flexible AC Transmission Systems: Modeling and Control"

The proposed operation (and forecasted operation) of projects with APFC devices as detailed in the technical considerations and modeling specification sections will have a direct influence on the overall impact of the project. These considerations must be included in the anticipated benefit and overall cost of project proposals including APFC devices.

PJM has evaluated the use of APFC devices within both the Generation Interconnection and Market Efficiency competitive planning processes. To date, no APFC device is currently in operation within the PJM footprint. As previously stated, however, PJM has incorporated other FACTS devices throughout the PJM system including in its operations, markets and planning functions.

Technical Considerations

Technical considerations should be evaluated in terms of proposed uses for APFC devices on the transmission system. Pursuant with FERC Order 2023 and FERC Order 1920, PJM considers APFC devices similar to other types of conventional fixed, switchable and FACTS devices already in use across the PJM system. PJM believes that the APFC devices may be evaluated to assess the benefits, costs and risks for implementation on the transmission grid considering planning, operations and markets impacts as well as interactions with neighboring ISOs/RTOs. PJM recommends that proposed APFC device applications be circumscribed as follows:

1 | It does not create other thermal, voltage, short circuit, transient stability concerns on other parts of the system.

2 | It does not result in adverse impacts to real time operations or markets. The APFC device application should provide adequate system margin for all operating conditions (thermal, voltage, short circuit and transient stability).

3 | It does not adversely impact external RTO/ISO facilities, real time operations, or markets.

4 | A conventional transmission upgrade is not feasible or is grossly uneconomical (e.g., public opposition, right-of-way/siting constraints, time to construct, etc.) and there is a practical/feasible location for the APFC device.

5 | The impacted TO is willing and able to own, operate and maintain the device.

6 | If it is anticipated that the overloaded line would need to be rebuilt due an “end of life” condition assessment, then the APFC solution may not be favorable.

7 | The total cost of the APFC device(s), plus any required spare equipment, does not exceed traditional facility reinforcement costs.

In addition to the above considerations, PJM in coordination with the impacted TO will also assess additional impacts to system complexity and security risks (vulnerability to cyber attached/physical security concerns) in its evaluation. PJM in coordination with the impacted TO will also consider any concerns if there is lack of redundancy and what operational measures may be needed if the device is out for maintenance or fails.

It should also be noted that a reinforcement solution addressing multiple needs, or drivers, across all study disciplines and analysis (e.g., could address more than one thermal, voltage, short circuit or transient stability concern) may be preferred. PJM in coordination with the TOs will assess all reinforcement options with the considerations above and select the most robust and effective network upgrade for the system.

For Interconnection Cycle studies, PJM runs reliability analysis per PJM Manual 14B and identifies NERC TPL-001, PJM Planning Criteria and Transmission Owner (TO) (FERC Form 715) planning criteria violations. For reinforcements needed for Interconnection Cycles, PJM will coordinate with the TOs on the most effective reinforcement solution for the Cycle projects. PJM will then test that upgrade to ensure it adequately addresses the criteria violation, does not create any new problems and is the best long-term, cost-effective solution for the Cycle.

For RTEP reinforcements, PJM will either:

1 | Work with the TOs to identify the best reinforcement solution, or

2 | Open an RTEP window to solicit for reinforcements to be evaluated with the same goal in mind.

Ultimately the impacted TO will need to determine if the installation of such a device is an acceptable addition to their transmission grid since the TO will own the equipment and be responsible for its maintenance and operations. PJM will accordingly evaluate the application of such APFCs from a more holistic approach considering operational flexibility, complexity and alignment with overall transmission expansion needs of the PJM system.

Projects that meet one or many of the above technical considerations do not necessitate the use of APFC device, but rather suggest a consideration of possible use and further evaluation.

Advanced Power Flow Controllers – Evaluation Matrix

	In Use in PJM Today	Potential Opportunity	Not Currently Applicable
Congestion Management		▲	
Thermal Support		▲	
Voltage Support		▲	
Stability Support		▲	
Generation Interconnection		▲	
Economic Planning		▲	
Long-Term Reliability Planning		▲	

Modeling Considerations

PJM currently expects to model APFC devices as PJM-controllable devices in all types of reliability and market analysis and across all seasonal studies. These devices may be modeled using similar methodologies for other types of conventional fixed, switchable and FACTS devices already in use across the PJM system. When these devices are proposed as mitigations to system planning reliability violations, the devices will need to be evaluated in accordance with all NERC Transmission Planning Reliability (TPL) standards and PJM planning criteria across all study domains. Discrete operating parameters for the devices must be considered as it relates to the specific criteria violation(s) being addressed.

When these devices are proposed along with the corresponding electrical and operating parameters as required to establish the basis for use in PJM system planning studies, the device must be studied to ensure it addresses all applicable criteria violations it is expected to mitigate, including acceptable operational performance, as well as identifying any ancillary benefits. As part of this study process, PJM will also evaluate these devices to ensure they **do not contribute** to new issues and/or exacerbate existing issues on the PJM system (e.g., "Do No Harm" analysis).

As it relates to PJM's operations, markets and planning functions, a unified modeling approach will need to be taken to ensure these devices are studied and operated as expected by PJM and the TO. Evaluating proposals, implementation in system modeling, and the operation of these devices will need to be compliant with all applicable PJM manuals, PJM instructions, and asset owner specifications.

Potential Benefits

APFC devices aid in the redistribution of flow across an existing infrastructure by "pushing" and "pulling" on pre-identified lines in order to help alleviate thermal overloads. The use of discrete operating parameters allows for controlled and studied actions to the changing needs of the system as they may vary throughout the day. Doing so may result in reduced congestion costs and/or increased output from least cost generation. Additionally, APFC devices can be used for the purpose of enhanced grid stability via voltage control and reactive power compensation. Helping maintain voltage levels within acceptable ranges can help prevent voltage sags and surges that can disrupt sensitive equipment. By improving power factors and reducing losses, APFC devices can enhance the overall stability of the local network.

As a potential single solution to address multiple facility overloads as well as transmission planning reliability violations, the use of APFC devices can impact overall costs and timelines associated with infrastructure investments. The scalability of devices may also help reduce costs and be used to avoid or defer more costly facility upgrades and/or network topology changes. Dependent on study results, the number of APFC devices can be specifically sized to address the violation(s) identified. In addition to the scalability benefits, the speed at which devices can be initially installed, added to, or removed to suit the specific needs provides additional flexibility in terms of transmission expansion, or in the case of outage management.

Identified Barriers

System Capacity and Operational Flexibility Remains Limited

Although APFC devices can help alleviate thermal overloads and increase system stability, they do not increase overall system headroom. As a result, the APFC device could shift flows to other parts of the system, reducing system margins on some facilities while increasing it on others and delaying longer-term critical conventional facility upgrades. This essentially shifts congestion without fully mitigating it.

> *Without added system capacity, operational flexibility is limited, which constrains the ability for operators to effectively respond to unexpected contingency events and maintenance outages.*

Potential Market Impacts

While discrete operating parameters may allow for PJM and TOs to study near-term impact of APFC devices, there are potential market impacts dependent on the ability to model and forecast device operation across existing reliability and market constructs working independent of PJM and TO operations.

Lack of Implementation History

Currently there are no APFC devices installed and operating on the PJM system along with limited deployments across the other interconnections within North America.

Lack of precedent upon which to understand how the APFC devices will perform introduces unknown risks onto the bulk power system. Limited exposure initially comes with risk from uncertainty on the modeling, operation and overall experience of the devices. It also implies unknowns to the potential barriers for implementation. Reliance on a limited number of currently available APFC vendors can introduce additional risk.

Increased Operational Complexity and Reliability Risks

Managing the system in real time can become increasingly complex as multiple APFC devices are installed on the transmission grid.

Increased operational complexity and lack of experience from PJM and TO operators introduces unknown reliability risks onto the grid.

The system can be exposed to APFC device mis-operations due to potential communication failures resulting in real impacts to the system such as facility outages. Operational and modeling complexities may increase as additional dynamic and variable devices are installed across the system with potentially conflicting optimization objectives for each device.

Expanded Cyber Attack Vulnerability

The grid system can also be exposed to an increase in cyber vulnerabilities through reliance on remote and advanced communication and control systems for the APFC devices. Protection against potential cyberattacks may be challenging.

Lack of Redundancy

The APFC device lacks redundancy outside of the built-in component redundancy of the device itself. A device failure can compromise the system and leave the system operator with a constrained grid and restricted operational responses in anticipation of the next contingency.

High Initial Investment Costs

The initial investment in an APFC device is significant, and there may also be additional operating and maintenance costs associated with multiple devices. Any associated ongoing and/or maintenance costs as well as necessary initial investment in APFC devices should be considered within a cost benefit analysis. This analysis should consider the potential system shifts and needs for additional system upgrades prior to implementation.

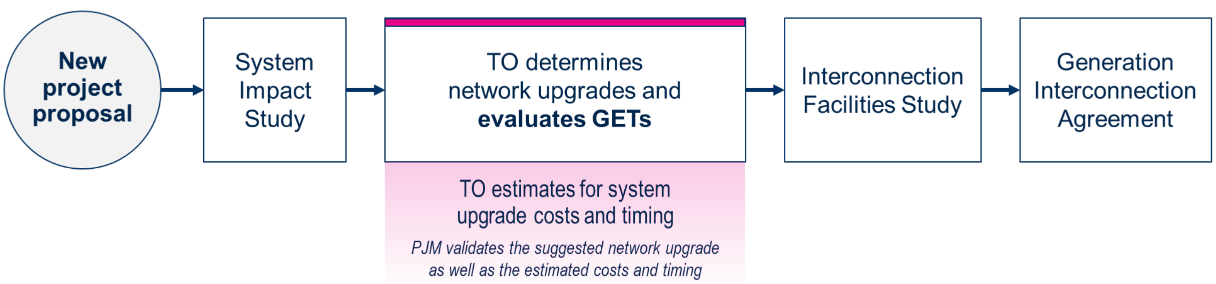
FERC Order 2023

On July 28, 2023, the Federal Energy Regulatory Commission (FERC) issued Order 2023,[1] a Final Rule adopting reforms to address interconnection queue backlogs and promote new technologies through its forms of generator interconnection procedures and agreements. In addition to ordering reforms to implement a first-ready, first-served cluster study process, the Commission addresses reforms to incorporate technological advancements into the interconnection process. The Final Rule requires transmission providers to evaluate, though *not* deploy, alternative transmission technologies in their cluster studies such as static synchronous compensators, static VAR compensators, advanced power flow control devices, transmission switching, synchronous condensers, voltage source converters, advanced conductors and tower lifting including any in any studies and re-studies.

The Final Rule emphasizes that the transmission provider will retain the sole discretion to determine, consistent with good utility practice, applicable reliability standards and other applicable regulatory requirements.

The Final Rule also requires that transmission providers include in their feasibility study reports and system impact study reports an explanation of the results of the evaluation for each of the aforementioned alternative transmission technologies for feasibility, cost and time savings as an alternative to a traditional network upgrade and whether a specific alternative technology should be used. **Figure 3** details when GETs are evaluated within a simplified generation interconnection process.

Figure 3. Simplified Generation Interconnection[2] Flowchart Considering GETs



PJM seeks an independent entity variation with respect to the Final Rule's requirement that transmission providers include in interconnection study reports the results of their evaluation of the feasibility, cost and time savings of GETs as an alternative to traditional transmission technologies.

In accordance with PJM's FERC Order 2023 and 2023A compliance filing,[3] the PJM Tariff already accounts for alternative transmission technologies in the interconnection process, as all of the enumerated GETs already are considered and studied, as necessary in the course of interconnection studies in the PJM region.

[1] FERC Order No. 2023

[2] Generation Interconnection Fact Sheet, PJM Interconnection

[3] Order Nos. 2023 and 2023-A Compliance Filing of PJM Interconnection

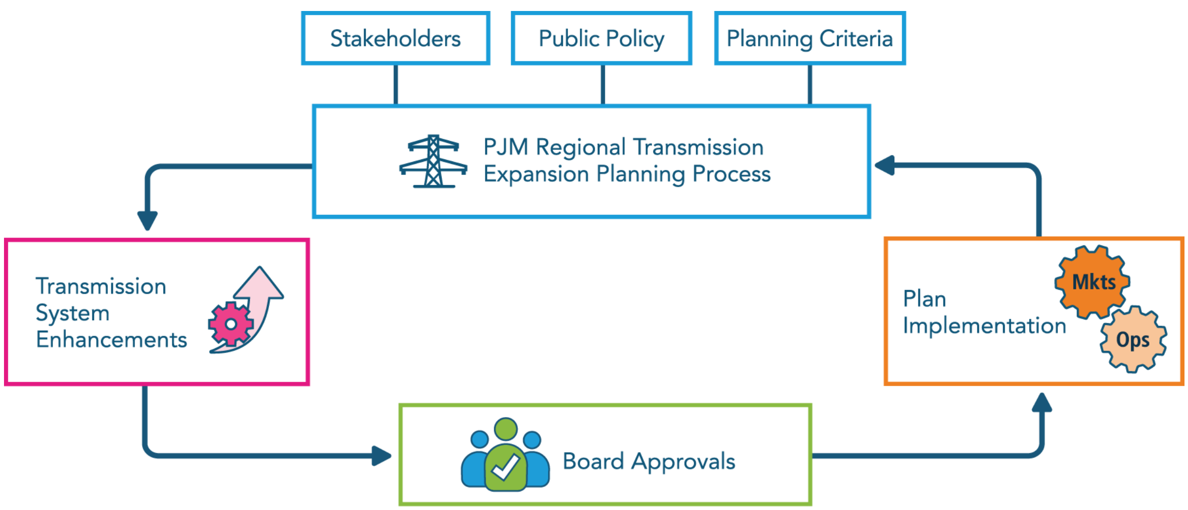
FERC Order 1920

FERC Order 1920[4] requires transmission providers to consider dynamic line ratings, advanced power flow control devices, advanced conductors and transmission switching for each identified transmission need in long-term regional transmission planning (LTRTP) and existing FERC Order 1000 regional transmission planning processes. The Order requires transmission providers to consider each of the enumerated technologies when evaluating new regional transmission facilities, as well as upgrades to existing transmission facilities, and explain in sufficient detail why any of the enumerated technologies are not selected. The selection and use of any of the technologies that are incorporated into an existing transmission facility (existing substation) should be treated as an upgrade to an existing transmission facility. Therefore, an incumbent transmission owner would be designated. For a new selected regional transmission facility, the transmission developer (incumbent or nonincumbent) is designated.

PJM is prepared to account for the operation and study of transmission switching in compliance with FERC Order 1920 as issued on May 13, 2024. A key consideration is that benefits for all projects be calculated on the same time horizon to allow for the ability to properly compare projects.[5] As such, PJM will require a time horizon that covers, at a minimum, 20 years starting from the estimated in-service date when comparing proposals within the LTRTP process. Projects including alternative transmission technologies proposed in an Order 1000 window will be evaluated over existing time horizons. As with all GETs, PJM recommends that proposals evaluate the technical considerations laid out in this technical reference guide as it applies to the identified issue.

Within the Regional Transmission Expansion Plan (RTEP), it is incumbent on the proposing entity to evaluate and suggest the use of advanced power flow controller, or any other GETs. As described in **Figure 4**, PJM receives input from states and other stakeholders, and in conjunction with the planning criteria, identifies the baseline projects. Proposing entities are then able to submit, for PJM consideration as part of the RTEP process, transmission system enhancements that may include, among other things, transmission switching and GETs.

Figure 4. RTEP Process – RTO Perspective



[4] FERC Order No. 1920: Building for the Future Through Electric Regional Transmission Planning and Cost Allocation, 187 FERC ¶ 61,068, at P 187

[5] FERC Order 1920, ¶848