

Flow Control Capabilities of Phase Angle Regulators (PARS) Installed Between Adjoining Power Pools, Past Treatment of PARs As Flow Control Devices and Areas for Additional Study Under the PJM Tariff and Manuals

Stan Gray – Pattern Energy Group

Kenneth Carretta – PSEG Energy Resources & Trade LLC

Planning Committee

Firm Injection Rights and Firm Withdrawal Rights Meeting

March 6, 2015

Purpose of this Presentation

- PJM reads its Tariff to mean that Phase Angle Regulator (PARs) technology *cannot* “effectively enable the controllable facilities to be operated as if they were direct current transmission facilities.”
- Problem Statement addresses:
 - Whether the PJM Tariff currently allows or should be modified to allow PARs to qualify as “Controllable AC Merchant” facilities.
 - What studies or procedures would be needed to determine awards of Firm Withdrawal Rights or Firm Injection Rights to a PARs project.
- This presentation provides education by offering background information and by identifying potential focus areas for future discussion:
 - PARs performance.
 - PARs capabilities and characteristics.
 - Previous treatment of PARs technology within the PJM footprint.
 - Alternate potential interpretations of the PJM Tariff.
 - Specific aspects of PARs capabilities and characteristics that may merit particular attention for future discussion.

Basic Operation of Phase Angle Regulating Transformers

- Because the current flow on a transmission link is proportional to the sine of the angle between the two line ends. Phase Angle Regulating transformers (PARs) are often used in power systems to control the active power flow (MW) in branches in meshed networks or to control the active power flow at the interface between two large and stiff independent grids. The control of MW flow is achieved by adjusting the phase angle of the voltages at the phase-shifting transformer terminals.
- Phase-shifting transformers built for transmission grids are generally a three-phase, two-terminal pair design. The terminal where power is injected into the transformer unit is called the “source terminal” and the power where load is exiting the transformer unit is called the “load terminal.”
- The change in phase angle between the terminal voltages of the transformer unit is carried out by adding a regulated voltage to the phase-to-neutral voltage at the source terminal.
- A winding in series with a network branch is used to insert the regulated voltage that, when added with the appropriate phase to the source terminal phase-to-neutral voltage, sets up the desired direction of the active power flow between the transformer terminals.

Illustration of Symmetric Phase-shifting Transformer

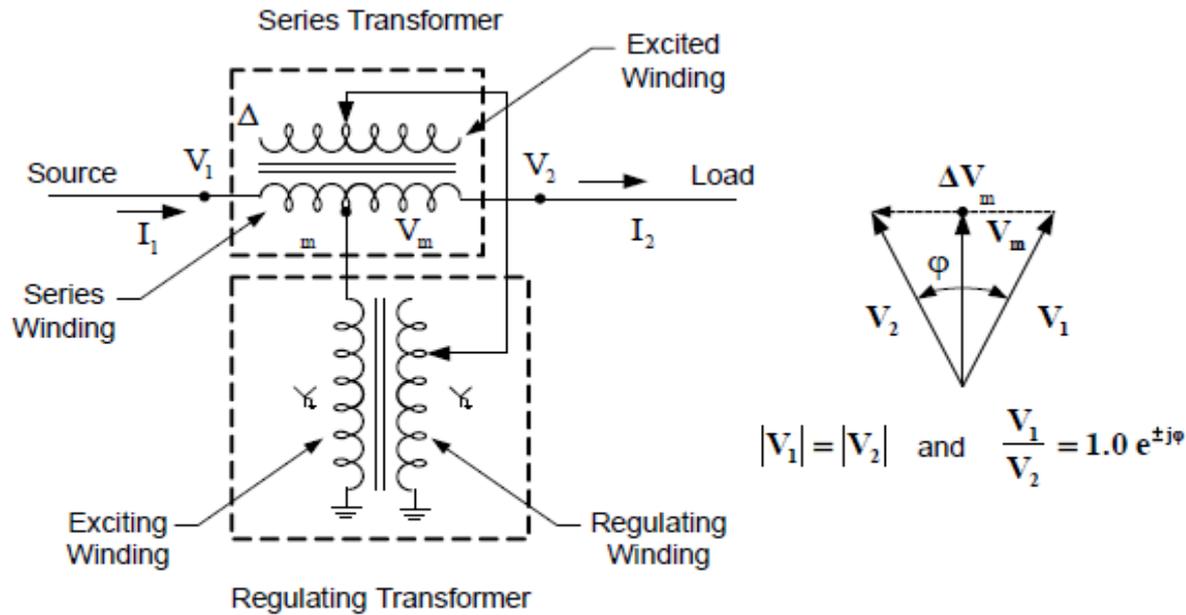


Figure 1 - Symmetric Phase-shifting Transformer

For an alternating current transmission line, power flow through the line is proportional to the sine of the difference in the phase angle of the voltage between the transmitting end and the receiving end of the line.

Capabilities of Modern PAR Technology

- **Control of Flow:**
 - PARs technology can reliability control power flows in a single direction or bi-directionally, provided that the magnitude of the induced phase angle is sufficient to address the system conditions encountered at the source.
 - Generally available equipment have phase angles capabilities between ± 20 and ± 60 degrees depending on the PAR size. A 550 MVA unit would have up to 50 degrees of regulation in 32 steps.
- **Precision:**
 - The level of precision will vary depending on the size of the facilities and the number of degrees.
 - Utility sized PARs are generally capable of maintaining flows within 3% to 4% of total capability.
- **Frequency of “Tap Changes”**
 - The number of available “tap changes” on modern PARs facilities can be between 750,000 and 1.2 million operations depending on loading during tap changes which would allow 50-80 “tap changes” per day over a 40 year useful life. Inspections are required on a 2 to 3 year cycle.

Capabilities of Modern High Voltage Direct Current Systems

- Set direction and magnitude of flow between terminals
- Can be designed to force flow in one direction or can be designed so the direction of power flow can be reversed
- Generally provides control of flow somewhat independent of the condition of the surrounding grid. HVDC remains as set after most N-1 events

Comparison Between Capabilities of PAR Technology and Direct Current Technology

CHARACTERISTICS	PAR TECHNOLOGY	DIRECT CURRENT
Flow Control Capability	Capable of providing reliable bi directional power flows, provided that size of equipment and phase angle “range” are adequate	Reliable power flow capability that can be designed as a unidirectional or bi directional system
Precision	Flows can generally be calibrated within 3-4% of desired target flow	Flows can be controlled to levels very close to settings
Availability	Available tap changes on large modern PARs can be as high as 1.2 million operations with a theoretical maximum of 50-80 tap changes per day; 2 to 3 year inspection cycle requiring de-energization	DC equipment must be taken out of service for several days to a week per year for maintenance

Previous Treatment of PARs Technology Within the PJM Footprint – PJM/ConEd Wheel

- Wheel from J/K to B/C Lines and with power flows controlled by four 345 MW PARs was deemed to be the “full functional equivalent of the [alternative] dc plan” analyzed in 1975 PSE&G/Con Edison joint study
 - Sufficiency of control capability studied under various contingencies for normal and emergency conditions and for “less probable contingencies.”
 - Study specifically considered adequacy of degree range on PARs to effectuate desired flows from PJM to New York.
 - Wheel protocols include limits on numbers of daily tap changes
- PJM “rolled over” these arrangements as firm transmission contracts in 2012
 - As described by PJM in its 2008 filing at FERC, “the adjustment of phase angle regulators (“PARs”) between NYISO and PJM [] enable the power to flow where desired.” May 28, 2008 “Answer of PJM,” filed in Docket No. ER08-858-000.

Previous Treatment of PARs Technology Within the PJM Footprint – Cavallo Power

- Queue Q75 was an interconnection submitted by Cavallo Power of a 1200 MW (phase 1 = 650 MVA) Phase Angle Regulated connection between the Public Service Bergen station and Consolidated Edison's 49th Street substation.
- Under PJM's System Impact Study (February 2008): "The #Q75 Bergen project which is an AC circuit with Phase Angle Regulator control was modeled connected to the Bergen 230kV substation. The project was studied as a 1200 MW firm withdrawal from Bergen at unity power factor." (The 1200 MWs request for Firm Withdrawal Rights was later amended to 1000 MWs.)
- Tests were conducted for generator and load deliverability and for "multiple facility contingency" including N-2 violations; short circuit and stability analyses would have occurred in the Facilities Study.
- *Results of study indicated that FWRs could be supported if transmission upgrades were constructed.*

PJM Tariff Provisions

- Controllable A.C. Merchant Transmission Facilities are defined as follows:
 - Transmission facilities that (1) employ technology which Transmission Provider reviews and verifies will permit control of the amount and/or direction of power flow on such facilities to such extent as to effectively enable the controllable facilities to be operated as if they were direct current transmission facilities, and (2) that are interconnected with the Transmission System pursuant to Part IV and Part VI of the Tariff.
- PJM has interpreted its Tariff to mean that PARs technology *cannot* “effectively enable the controllable facilities to be operated as if they were direct current transmission facilities”

PJM Tariff Provisions (con't)

- Grounds for an alternate interpretation of the PJM Tariff include:
 - Requirement that controllable AC facilities “*effectively* enable . . . operat[ion] as if they were direct current transmission facilities” contemplates examination of how “*effectively*” particular AC projects may provide similar service as DC.
 - Functional capabilities of PARs and DC projects in practical operations may be comparable in terms of precision, number of allowed operations and flow control.
 - Case-by-case determination of projects and surrounding facts could be used to evaluate “effectiveness” as has occurred in the past within the PJM footprint.

Areas For Additional Study and Consideration

- Consider whether Tariff language is broad enough to cover treatment of PARs as Controllable A.C. facilities and accordingly need not be changed.
- Consider amending Manual to include specific criteria for determining “effectiveness” of particular PAR technology proposals:
 - Establish criterion for “precision” of acceptable flow control.
 - Establish criterion for determining sufficiency of allowed operations over expected life of PARs.
 - Establish criterion requiring demonstration that “angle range” of proposed PARs is sufficient to meet studied system conditions.