# AEP Methodology for Generator Reactive Power Supply Compensation

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# Background

- AEP filed a transmission and ancillary services rate case in April 1993 in Docket No. ER93-540
- FERC accepted and set the case for hearing in September 1993
- Before hearings commenced, FERC issued Open Access NOPR in March 1995
- Order 888 issued in April 1996, established non-price terms and conditions for open access transmission service
- AEP submitted a new tariff in compliance with Order 888
- Price issues for transmission service and ancillary services ultimately settled in Opinion 440 issued on July 30, 1999

# Background

- Order 888 established Reactive Power Supply as a required ancillary service for transmission service customers
- Transmission Provider must offer, and Transmission Customer must purchase
- Since reactive power doesn’t travel very far, supplies must be located near the area of need on the transmission system
- Generators or other sources of reactive power have locational market power due to the difficulty of transporting reactive power
- Reactive Power Supply is therefore priced as a cost-of-service based product, not market based
- AEP rate case established a methodology for determining the cost of providing reactive power from synchronous generation sources

# AEP Methodology

- AEP was developed in the context of a FERC jurisdictional utility using the Commission's Uniform System of Accounts (USoA)
- AEP considers costs in four groups of plant investments
  - Generators and Exciters – Accounts 314, 323, 333, and 344
  - Accessory Electric Equipment (AEE) that supports the generators/exciters – Accounts 315, 324, 334, and 345
  - Generator Step-up Transformers
  - Remaining Production Plant investment

# Generators and Exciters

- Turbine, Generator, and Exciter costs are generally booked as one piece of equipment in Accounts 314, 323, 333, and 344
- AEP used cost information from the turbine generator manufacturer to separate the cost of the turbine from the generator/exciter (based on the cost of a spare machine)
- AEP determined 60% of the turbine, generator, exciter set was attributable to the turbine and 40% was attributable to the generator and exciter
- AEP had other costs booked to Account 314 which were not part of the turbine generator/exciter set, e.g., water treatment, circulating water system, etc.
- Removing these costs, AEP determined 65.6% of the costs in Account 314 were associated with the turbine generator.
- Resulting allocation of Account 314 costs to the generator/exciter was therefore 65.6% x 40% = 26%

# Accessory Electric Equipment (AEE)

- AEP analyzed the costs and equipment in all the Account 315 sub-accounts to determine the percentage allocated to equipment that supports the operation of the generators/exciters. For example:
  - Spare Elec Equipment: 20% for switchgear, aux transformer, gen CTs
  - Batteries: 30% for supply to $H^2$ seal oil pumps, dc lube oil pumps, dc controls
  - Bus and Insulators: 80% for Iso-phase bus, exciter bus
  - Control Cables: 30% for control cabling for gen/exciter
  - Power Cables: 5% for gen/exciter auxiliaries
  - Cable Tray and Conduit: 10% for applicable control and power cable
  - Station Grounding: 25% for grounding of generator
  - Structure: 10% for supports for electric equipment associated with generator
  - Switch Board Equipment: 30% for gen controls, protective relays, annunciator
  - Switching Equipment: 10% for breakers serving gen/exciter auxiliary equipment
  - Transformers: 10% for transformers serving gen/exciter auxiliary equipment
  - Start-up Power Supply: 10% for supply to gen/exciter auxiliary equipment

# Accessory Electric Equipment

- The analysis revealed a range of 11% to 19.6% of the costs in Accounts 315, were for equipment that supports the operation of the generators/exciters in the various AEP generating plants
- AEP used 10% as a conservative estimate to apply to all their facilities

# Accessory Electric Equipment

- Intervenors challenged the 10% allocation, so AEP conducted a more detailed analysis which found some errors and resulted in some changes to the allocations:
  - Batteries: changed from 30% to 29%
  - Bus and Insulators: changed from 80% to 87%
  - Switch Board Equipment: changed from 30% to 20%
  - Switching Equipment: changed from 10% to 7%
  - Transformers: changed from 10% to 3%
- The more detailed analysis resulted in an overall AEE allocation range of 14.94% to 18.48% with a weighted average of 17.25%
- AEP decided to stay with its original allocation of 10% as a very conservative estimate

# Reactive Power Allocation Factor

- Since the Generators/Exciters, AEE that supports the gen/exc, and GSU transformers support both real and reactive power production from a generator, AEP applied an allocation factor to allocate the costs to both real and reactive power production
- Allocation factor comes from the equation: $MW^2 + MVAR^2 = MVA^2$
- Therefore, $MW^2/MVA^2 + MVAR^2/MVA^2 = 1$
- The allocation factor for reactive power is thus $MVAR^2/MVA^2$
- This factor is multiplied by the costs of the generators/exciters, AEE that supports the generators/exciters, and GSU transformer to get the investment allocated to reactive power production

# Remaining Production Plant Investment

- Since the excitation system consumes real power during reactive power production, AEP allocated a portion of the remaining plant investment
- Allocation factor was calculated as a ratio of Exciter MW/Generator MW times Max VAR Production/Nameplate VAR
- The second ratio was added to reflect the diversity in a fleet of resources serving a network load.  Subsequent cases state that the second ratio does not apply for a single generator applying for reactive compensation
- AEP calculated a ratio of 0.2%

# Remaining Production Plant Investment

- Rebuttal testimony included a more accurate means of determining the ratio by calculating the increased generator losses incurred during reactive power production.
- The increased losses include generator field losses, armature losses, and GSU transformer losses caused by the increased currents from reactive power production.
- The loss calculation involves using the generator V-curve to obtain the field current at zero VAR and rated VAR production to get the difference in field losses.
- Then the difference in armature current at zero VAR and rated VAR production is used to calculate the difference in armature losses and GSU transformer losses.
- These losses are summed, and a share of the no-load losses are added. Share of no-load loss is allocated by the reactive power allocation factor. Total is the increased losses from reactive power production.
- The more accurate calculation resulted in the same 0.2%

# Remaining Production Plant Investment

- Supplemental testimony recognized that the GSU transformer losses were already being recovered in AEP's transmission rate
- Removing the GSU transformer losses resulted in an allocation factor of 0.15%
- Final allocation factor for Remaining Production Plant Investment, or Balance of Plant (BOP) allocation factor, was 0.15%

# AEP Methodology Applied by Subsequent Generators

- Since AEP Order was issued, FERC has instructed other generators that have detailed cost information to use the AEP Methodology to determine their costs for reactive power supply
- Generators typically perform their own analysis to determine their specific:
  - Generator/Exciter total investment
  - AEE investment that supports the generator/exciter
  - GSU transformer investment
  - Reactive Power Allocation factor
  - Balance of Plant allocation factor

# Annual Revenue Requirement

- Total Reactive Investment is the sum of:
  - Generator/Exciter investment times Reactive Power Allocation Factor
  - AEE investment that supports the gen/exciter times the Reactive Power Allocation Factor
  - GSU investment times the Reactive Power Allocation Factor
  - Remaining Production Plant investment times the Balance of Plant (BOP) allocation factor
- This total investment is then multiplied by the annual fixed charge rate to arrive at an Annual Revenue Requirement for Reactive Power Supply

# Application of AEP Methodology to Wind and Solar Generation Technology

- AEP Methodology can be applied to Wind and Solar generators by comparing the function of the plant components to those of a conventional synchronous generator
- Wind and Solar generators still have a generator and exciter
  - Type 3 Wind Turbine Generators (WTG) with induction generator and converter
  - Type 4 WTGs with induction generator and full-size inverter
  - Solar Inverters
- Type 3 and Type 4 WTGs produce reactive power through the generator and converter or the full-size inverter
- Solar inverters produce reactive power

# Application of AEP Methodology to Wind and Solar Generation Technology

- Wind and Solar Generator/Exciter costs can be isolated from the total plant costs using cost allocations provided by the manufacturers just as in AEP
- Since most wind and solar generators don't use the Commission's USoA, the individual accounts used by the generator owner are analyzed to determine the applicable costs
- AEE that supports the operation of the generators is also determined on a functional basis, just as in AEP. The most significant AEE is the collection system which is equivalent to the generator bus in a synchronous plant.
- The equivalent of the GSU transformer is also identifiable in the wind and solar facility. The GSU transformer steps up the voltage to the interconnection voltage, often located in a collection system substation.
- Each of these items and their costs are allocated to reactive power production by the same reactive power allocation factor used in AEP; $MVAR^2/MVA^2$

# Application of AEP Methodology to Wind and Solar Generation Technology

- Balance of Plant (BOP) allocator can be functionally determined the same way as in AEP.
- BOP allocator is calculated by determining the increase in losses caused by reactive power production.
- Due to the complexity of a wind generating facility, a power flow model is often used to determine the increase in losses
- The power flow model is run with two cases, one with zero reactive power production and one with rated reactive power production. The difference in the net output of the plant is the increase in losses.
- A share of the no-load losses from the individual transformers and the GSU transformer can be added to arrive at the total impact and the BOP allocator

# Annual Revenue Requirement for Wind and Solar Generation

- Total Wind and Solar Reactive Investment is the sum of:
  - Generator/Exciter investment times Reactive Power Allocation Factor
  - AEE investment that supports the gen/exciter times the Reactive Power Allocation Factor
  - GSU investment times the Reactive Power Allocation Factor
  - Remaining Production Plant investment times the Balance of Plant (BOP) allocation factor
- This total investment is then multiplied by the annual fixed charge rate to arrive at an Annual Revenue Requirement for Reactive Power Supply

# Questions or Comments


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