Jack E. Jirak
Associate General Counsel

Mailing Address:
NCRH 20 / P.O. Box 1551
Raleigh, NC 27602

o: 919.546.3257
f: 919.546.2694

Jack.Jirak@duke-energy.com

March 15, 2021

VIA ELECTRONIC FILING

Ms. Kimberley A. Campbell, Chief Clerk
North Carolina Utilities Commission
4325 Mail Service Center
Raleigh, North Carolina 27699-4300

RE: DEC and DEP's Annual IEEE Standard 1547-2018 Implementation Status Report
Docket Nos. E-100, Sub 101 and E-100, Sub 101B

Dear Ms. Campbell:

Enclosed for filing with the North Carolina Utilities Commission ("Commission") on behalf of Duke Energy Carolinas, LLC ("DEC"), and Duke Energy Progress, LLC ("DEP" and together with DEC, "Duke" or the "Companies") is the Companies' *Annual IEEE Standard 1547-2018 Implementation Status Report*, in response to the Commission's March 2, 2021 *Order Requiring Reports and Scheduling Presentation* ("IEEE 1547 Informational Order").

Background

IEEE Standard 1547 is a technical standard that is published by the IEEE Standards Association ("IEEE SA") for the uniform interconnection and interoperability of distributed energy resources ("DER") with electric power systems.

On June 14, 2019, the Commission issued its *Order Approving Revised Interconnection Standard and Requiring Reports and Testimony* in Docket No. E-100, Sub 101 (2019 Order) which, among other things, required the electric utilities to host stakeholder meetings on IEEE Standard 1547-2018 and to file a report with the Commission by April 1, 2020. On April 1, 2020, the Companies filed the required report explaining their IEEE Standard 1547-2018 implementation efforts.

On March 2, 2021, the Commission issued its IEEE Informational Order, advising that the Commission would like to stay informed of IEEE Standard 1547-2018 implementation efforts in North Carolina and, therefore, requesting that the Companies annually file: (A) the most recent version of IEEE Standard 1547, (B) the most recent version of the Companies' Implementation Guidelines, and (C) a narrative explanation of any stakeholder meetings that have occurred since the Companies' previous filing. In accordance with the IEEE Informational Order, the Companies hereby provide the Commission the requested information.

Annual Report for 2020-2021

(A) The *IEEE 1547-2019 – IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces* developed and published by the IEEE SA is a copyrighted standard that is not publicly available for reproduction and distribution. The Companies are therefore unable to publicly file a copy of IEEE Standard 1547 with the Commission. The IEEE Standard 1547 is available at the following link: https://standards.ieee.org/standard/1547-2018.html and additional information about procuring a copy may be obtained by contacting IEEE SA.

(B) Included as Attachment A to this letter is a copy of the Implementation of IEEE 1547-2018 Guidelines for Duke Energy Carolinas and Duke Energy Progress ("Guidelines"). This is Revision 3 of the Guidelines as most recently updated on January 20, 2021. The narrative descriptions of the Companies' stakeholder meetings concerning the IEEE Standard 1547-2018 illustrate that the Companies have received limited feedback from stakeholders regarding implementation despite consistent informational sessions being held during Technical Standards Review Group ("TSRG") meetings throughout 2020 and into 2021. The Companies have continued to make revisions to the Guidelines since Revision 0 was filed with the Commission on April 1, 2020.

(C) Implementation of the IEEE Standard 1547-2018 has taken place through the Companies' TSRG. The TSRG is a Duke-specific forum made up of North and South Carolina interested stakeholders that meets quarterly to address technical issues regarding the interconnection and operation of renewable generation in Duke's service territories. The quarterly TSRG meetings are held in January, April, July and October of each year and all meeting information is publicly available on the TSRG website, available at https://www.duke-energy.com/business/products/renewables/generate-your-own/tsrg. Since the filing of the Companies' last report on April 1, 2020, four quarterly TSRG meetings have occurred. However, because this is the Companies' first annual report, the Companies are providing narratives and copies of TSRG presentations having occurred since the Commission's 2019 Order that concerned the IEEE Standard 1547-2018. Copies of the TSRG presentations are included as Attachment B to this letter. The descriptions below summarize the actions and discussions at each TSRG meeting conducted since the 2019 Order.

May 2019 TSRG Meeting

Implementing smart inverter functions of the IEEE Standard 1547-2018 was first discussed during this meeting. Stakeholders noted some of the voltage and reactive power control functions and ride-through contained in the IEEE Standard 1547-2018, as well as noted that other utilities were considering adoption of portions of the IEEE Standard 1547-2018. Stakeholders expressed interest in the inverter-level functions and control during the meeting, stating that they viewed a wider area control as a future capability. Duke agreed with stakeholders that it was time to address the IEEE Standard 1547-2018, and the TSRG agreed that reactive power control was a priority and would be the first issue addressed.

September 2019 TSRG Meeting

Implementation of the IEEE Standard 1547-2018 was not an agenda item at this meeting. During the meeting Duke did, however, reiterate that scoping for a volt-var control study was under development. The study was specifically designed to address technical concerns about implementation of section 5.3 of IEEE Standard 1547-2018, "Voltage and reactive power control." Duke also introduced the possibility of a pilot program to evaluate the functions of a volt-var control study. The volt-var study discussed at this TSRG ultimately began in November 2019 and was concluded in March 2020.

January 2020 TSRG Meeting

At the beginning of this meeting, the need for prioritization of the many technical aspects of IEEE Standard 1547-2018 was discussed and Duke presented an initial "order of priority" to implement the standard. As discussed in a prior meeting, Duke proposed to prioritize voltage and reactive power control first and to address capability to limit active power at a later date. Duke also requested each TSRG member to rank the implementation priority of each section of IEEE Standard 1547-2018 in order to come up with a consensus priority list. However, Duke only received three rankings from TSRG members, with one of those members being the North Carolina Utilities Commission—Public Staff. Each of those recommendations were incorporated into the final priority list. Also at this meeting, several questions were posed by the Companies at the end of the presentation regarding IEEE Standard 1547-2018 implementation efforts generally. No significant discussion occurred amongst the TSRG members, though members agreed with Duke to continue to address implementation of IEEE Standard 1547-2018 at the quarterly TSRG meetings. Last, the intermediate results of the volt-var study were presented to the TSRG members, and extended discussion occurred on topics including power system model details, types of control, and study objectives.

Two presentations were shared during this meeting and are being filed with this report for the Commission's information:

- Action Plan to Implement 1547, January 21, 2020
- Duke Energy Inverter volt-VAR Functionality Study, January 21, 2020

April 2020 TSRG Meeting

Prior to this meeting on April 1, 2020, and as ordered by the Commission, Duke filed the initial version, Revision 0, of the Guidelines as well as a separate report entitled "Impact of Enabling Inverter Based Resource Reactive Power Controls." The Guidelines filed on April 1, 2020 (and those included with this filing) provide an overall roadmap for assessment and implementation of IEEE Standard 1547-2018 and is considered a "living" document to be updated over time as additional feedback is received and further studies performed. The Reactive Power Control Report is a detailed assessment of the volt-var controls of the IEEE Standard 1547-2018.

At the meeting, the final conclusions of the volt-var study and the recommended next steps were presented to the TSRG members. In addition, there was discussion about pilots and study objectives for possibly a second volt-var control study.

The prioritized order of IEEE Standard 1547-2018 sections that resulted from the Companies' poll of stakeholder rankings was also presented at this meeting along with the ranking criteria. There was no significant discussion by TRSG members on the presentation of the study or poll results, or the initial version of the implementation Guidelines from TSRG members. Two presentations were shared during this meeting and are being filed with this report for the Commission's information:

- Update and Discussion: Action Plan to Implement 1547-2018, April 28, 2020
- Update and Discussion: Inverter Volt-Var Impact Study TSRG Meeting, April 28, 2020

September 2020 TSRG

As requested by stakeholders, the July TSRG meeting was postponed several weeks and held in September, 2020. However, in July, Revision 1 of the Guidelines were forwarded to TSRG members for review and comment at the September meeting. A summary of the updates to the Guidelines were also provided to TSRG members through this communication. At the meeting, there was limited discussion about undervoltage tripping for abnormal system conditions, and Duke noted that those settings are part of an ongoing enterprise-wide protection setting review that seeks to standardize settings across all Duke operating areas. Duke also confirmed that the IEEE Standard 1547-2018 implementation schedule would be discussed within the TSRG and coordinated with DER owners once the scope of the implementation was better defined. During the meeting Duke also requested input on the Guidelines and noted the sections that were "completed."[1] Additionally, the unresolved issues and recommended next steps from the first reactive power study were discussed, and it was decided that Duke would perform a second reactive power study. The scope of the second study was then discussed. There was also discussion concerning the benefit of the reactive power control for the system and the DER, and it was reiterated that the focus of the study was utility-scale DER applications. Duke requested input at the meeting since there was no written comments to the Guidelines received prior to the meeting via email. Duke specifically asked for comments regarding the benefit of reactive power control for the system and the DER. No specific input was given during the meeting, but the North Carolina Clean Energy Business Alliance, a member of the TSRG, indicated that Duke was moving in the right direction and supported the study effort. Two presentations were shared during this meeting and are being filed with this report for the Commission's information:

- Update and Discussion: Action plan to Implement 1547-2018, September 2, 2020
- TSRG: Inverter Volt-VAR Study Scope Review, September 2, 2020

<u>October 2020 TSRG Meeting</u>

During this meeting, the IEEE Standard 1547-2018 implementation discussion focused on Revision 2 of the Guidelines. It was noted that the reactive power control studies were the only remaining outstanding "priority" group 1 topic. Seven additional IEEE Standard 1547-2018 sections were listed as "complete" in this revision. Much of the discussion during this meeting was around the reactive power capability section. Duke reiterated that requirements for the new inverters is not retroactive for existing inverters. Duke also provided a final review of the volt-var second study objectives and discussed the criteria used to select the study feeders. The initial suggestions on each type of reactive power controller and the variations of setting configurations were then discussed. Several more metrics were identified for this study and each was presented to the TSRG. The time series studies are a significant part of the study and the basics of the model were reviewed. A sample presentation of study results was also reviewed. As a result of these reviews,

[1] The "completed" status is assigned when Duke believes all the technical concerns regarding a particular issue have been included in the Guidelines and there should be enough technical direction then to begin defining the scope of implementation.

stakeholder discussion centered on how to evaluate the results and how to determine which controls are more effective. Two presentations were shared during this meeting and are being filed with this report for the Commission's information:

- Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting, October 28, 2020
- TSRG: Inverter Volt-VAR Study Update, October 28, 2020

<u>January 2021 TSRG</u>

The most recent TSRG meeting focused on Revision 3 of the Guidelines with respect to the discussion concerning IEEE Standard 1547-2018 implementation. Revision 3 includes updates addressing the discussions during the last TSRG meeting about reactive power capability. The work on the enter service requirements was also reviewed and discussed at this meeting. As a result of these discussions, the sections on current distortion and prioritization of DER responses were noted as "complete." Duke also addressed how performing a sequence of time series analyses requires more detailed power system modeling than that required for analysis at a single fixed load and generation level. These additional modeling details were reviewed with the stakeholders. Study results were also provided that described how the DER reactive power can interact with station voltage regulation devices. Some feeder study results were shared and the specific measures (metrics) for a controller were reviewed to highlight the attributes that improved and those that worsened when compared to the unity power factor basecase. No significant feedback was received from stakeholders during this meeting regarding the reactive power study. Two presentations were shared during this meeting and are being filed with this report for the Commission's information:

- Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting, January 20, 2021
- TSRG: Inverter Volt-VAR Study Update, January 20, 2021

<u>Forthcoming April 2021 TSRG Meeting</u>

At this time, the Companies are in the process of updating the Guidelines to account for discussions had during the January 2021 TSRG Meeting. The second quarterly TSRG meeting for 2021 is currently scheduled for April 28, 2021. Revision 4 of the Guidelines and the final results of the second reactive power study will be discussed during this meeting.

The Companies will be prepared to answer questions the Commission may have during the presentation before the Commission scheduled for Monday, April 12, 2021.

Thank you for your consideration in this matter. Please do not hesitate to contact me with any questions or concerns.

Sincerely,

Jack E. Jirak
Associate General Counsel

Enclosures

cc: Parties of Record

CERTIFICATE OF SERVICE

I certify that a copy of Duke Energy Carolinas, LLC and Duke Energy Progress, LLC's Annual IEEE Standard 1547-2018 Implementation Status Report, in Docket Nos. E-100, Sub 101 and E-100, Sub 101B, has been served by electronic mail, hand delivery or by depositing a copy in the United States mail, postage prepaid to parties of record:

This the 15th day of March, 2021.

Jack E. Jirak
Associate General Counsel
Duke Energy Corporation
P.O. Box 1551/NCRH 20
Raleigh, North Carolina 27602
(919) 546-3257
Jack.jirak@duke-energy.com

ATTACHMENT A

Implementation of IEEE 1547-2018 Guidelines for Duke Energy Carolinas and Duke Energy Progress
January 20, 2021

Docket No. E-100, Sub 101
Docket No. E-100, Sub 101B

Implementation of IEEE 1547-2018 Guidelines for Duke Energy Carolinas and Duke Energy Progress

Duke Energy

Duke Energy Carolinas and Duke Energy Progress

Distributed Energy Technology

DER Technical Standards

Revision 3

January 20, 2021

Implementation of IEEE 1547-2018 Guidelines for Duke Energy Carolinas and Duke Energy Progress

Revision	Date	Description
0	3/31/2020	Initial issue
1	7/21/2020	General update prior to July 2020 TSRG meeting
2	10/28/2020	General update prior to Oct. 2020 TSRG meeting
3	1/20/2021	General update prior to Jan. 2021 TSRG meeting

CONTENTS

INTRODUCTION

Duke Energy seeks to implement smart inverter technical specifications and requirements as defined in the updated IEEE Standard 1547-2018, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems (IEEE 1547 or the Standard). This document focuses only on the distributed energy resources (DER) connected to the distribution system and not those connected to the transmission or bulk power system (BPS). In North and South Carolina, the implementation of IEEE 1547 is focused on large utility scale DER (UDER) because there had been significant number of those installations. Some of IEEE 1547 requirements are also applicable to the smaller retail and residential DER (RDER). If there are any variations in application of the Standard to UDER and RDER, those conditions will be noted in this document.

> Note to the format of this document. This guideline is meant to be a living document. For now, it captures where Duke Energy is in the process of implementing IEEE 1547-2018. This document notes sections of the standard that require no additional analysis or review and those that are under review and those that must still be reviewed. In sections highlighted like this paragraph, there will be a brief discussion of the ongoing work to be concluded to address implementation of that Standard section.

The standard is an inverter Standard and not a utility standard, therefore many parts of the Standard can be implemented by Duke Energy simply by adopting IEEE 1547-2018 as the applicable standard for Duke Energy inverter based interconnections. However, there are some sections of the Standard that require input or specifications from the utility. The Standard specifies inverter capabilities and functions, but not utilization. The purpose of this document is to clarify any additional information for utilization.

The standard is applicable to DER connected at the primary or secondary distribution system voltage levels. However, some of the Standard requirements are based on conditions and issues related to the BES. There can be situations where the aggregate distribution DER capacities are large enough to impact the NERC BES reliability. In those cases, BES requirements are implemented in DER connected to the distribution system. However, these requirements are not directly distribution requirements, but BES requirements applied at the distribution power system level. The interaction between the BES and the distribution system is well covered in the NERC Reliability Guideline: Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018. The guideline recommends that the BPS entities (BA, RC, PC, TP) coordinate with the Distribution Providers (DP) to achieve successful implementation of the Standard.

This Duke Energy Guideline is applicable to DER located in the Duke Energy service territories in North Carolina and South Carolina. The Guidelines have been developed based on input and comments from TSRG stakeholders.

CONSIDERATION OF IEEE 1547 SECTIONS THAT COULD INCREASE INTERCONNECTION CAPABILITY

The following IEEE 1547 controls or functions are the primary functions that could potentially increase the amount of DER capacity (higher penetration) that can interconnect with minimal feeder upgrades:

i) 4.6.2 Capability to limit active power
ii) 5.3 Voltage and reactive power control
iii) 5.4 Voltage and active power control

While power quality issues can still restrict interconnection, the voltage and reactive power controls are a potential mitigation to those issues too.

While there are other inverter functions that improve reliability of the interconnection, the inverter functions listed above would be the primary drivers for adding more DER capacity to a feeder. Therefore, these functions were assigned a higher priority to review and analyze.

CONSIDERATION OF IEEE 1547 SECTIONS THAT IMPACT GRID SUPPORT

In addition to prioritizing assessment of those sections of IEEE-1547 that could increase interconnection capability, the Companies are also prioritizing those sections that could impact grid support. The 2003 version of the standard created reliability concerns by not providing voltage regulating capability and tripping for abnormal system conditions. While the 2014 version addressed some of the grid reliability concerns, 2018 provides even more inverter capabilities. Also, documents such as the NERC Reliability Guideline: Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018 focus "on ensuring reliable operation of the BPS under increasing penetrations of BPS-connected inverter-based resources as well as distributed energy resources (DERs)." One objective of such documents is to encourage timely adoption of the IEEE 1547-2018 that are likely to impact or support the BPS.

The priority of review of the Standard sections identified in the table is consistent with this industry guidance in that many of the first and second priority selected topics were noted in the NERC guideline as well. Sections 4.2 and 4.10.2 are fourth priority for Duke, but that is mainly because these topics are thought to be more straightforward to address and will likely not require significant evaluation. Interoperability was noted by NERC and Duke plans to address that on a topic by topic basis rather than as one stand-alone interoperability topic. In this way, interoperability is addressed concurrent with the technical considerations for each topic.

The following topics are yet unranked by Duke, but they are in the NERC guideline: 6.4.2.7, 6.5.2.8, 8.1, 8.2. Section 6.4.2.7 was added to the Duke list after the NERC guideline review. These were not ranked during the Duke process because of the lower priority placed on them by the TSRG stakeholders and Duke. These are also topics that need more time and investigation by the industry, so addressing some of the better understood and higher prioritized items first is a reasonable path forward.

PRIORITY OF IMPLEMENTING THE IEEE 1547 TECHNICAL SPECIFICATIONS AND REQUIREMENTS

There are many aspects of implementing the Standard that must be considered. The technical specifications and requirements must be understood and assessed to determine if there is a need to clarify any technical points for consistent application across the Duke system. Duke subject matter experts, TSRG stakeholders, NC Public Staff, and industry documents were included in the activity to set priority for the various Standard sections. The areas of the Standard that stand out as most important are the ride through capability and voltage and reactive power controls.

Below is the priority order at this time considering all TSRG input. If there is no priority stated in the list, then the priority of those items is yet to be assigned. Note that the priority group and the assigned Duke identification number[1] for that item are both in the first column. The remaining IEEE 1547-2018 clauses and sections that do not have a priority assigned will be undertaken following the completion of the higher priority topics. The three columns on the far right side of the table summarize the status for the technical, interoperability, and verification and test aspects for each Standard topic. Many of the summaries are not the final decision because the topic requires more analysis and assessment. However, this table still provides a general overview.

[1] Only the prioritized Duke identification numbers represent the sequence of evaluation, and are numbered less than 100. Numbers greater than 100 are temporarily assigned to the topic until that topic is given a specific priority.

Duke Energy Selected Order of Precedence for IEEE 1547 Sections

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
1 (DUK-01)	5.2	Reactive power capability of the DER	Category B 35° C ambient or higher at rated voltage	No Reqmt	Eval + Comm Test
1 (DUK-02)	5.3	Voltage and reactive power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-03)	5.4.2	Voltage-active power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-04)	7.4	Limitation of overvoltage contribution	Accept 1547 with additional requirements	No Reqmt	Eval + Comm Test
1 (DUK-05)	7.2.3	Power Quality, Flicker	Accept 1547 in conjunction with continued use of IEEE 1453	No Reqmt	Eval + Comm Test
1 (DUK-06)	7.2.2	Power Quality, Rapid voltage change (RVC)	Continue existing criteria and policy	TBD	TBD, Eval + Comm Test
2 (DUK-07)	6.4.1	Mandatory voltage tripping requirements (OV/UV)	Have existing setpoints; new 1547 setpoint study in progress	TBD	Eval + Comm Test
2 (DUK-08)	6.5.1	Mandatory frequency tripping requirements (OF/UF)	Have existing setpoints; new 1547 setpoint study in progress	TBD	Eval + Comm Test
2 (DUK-09)	6.4.2	Voltage disturbance ride-through requirements	Study in progress	TBD	Eval + Comm Test
2 (DUK-10)	6.5.2	Frequency disturbance ride-through requirements	Study in progress	TBD	TBD, Eval + Comm Test
2 (DUK-11)	6.5.2.7	Frequency-droop (frequency-power) capability	Evaluation has not begun	No Reqmt	TBD, Eval + Comm Test
2 (DUK-12)	6.5.2.6	Voltage phase angle changes ride-through	Study in progress	No Reqmt	TBD, Eval + Comm Test
3 (DUK-13)	4.5	Cease to energize performance requirement	Accept 1547 as written	No Reqmt	Eval + Comm Test
3 (DUK-14)	4.6.1	Capability to disable permit service	Accept 1547 as written	Yes	TBD, Eval + Comm Test
3 (DUK-15)	4.6.2	Capability to limit active power	Accept 1547 as written	Yes	TBD, Eval + Comm Test
4 (DUK-16)	6.5.2.5	Rate of change of frequency (ROCOF)	Study in progress	TBD	TBD, Eval + Comm Test

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
4 (DUK-17)	4.2	Reference points of applicability (RPA)	Accept 1547 as written; consider clarifications	No Reqmt	TBD, Eval.
4 (DUK-18)	4.3	Applicable voltages	Accept 1547 as written; consider clarifications	Yes	TBD, Eval.
4 (DUK-19)	4.10.2	Enter service criteria // 6.6 Return to service after trip	Accept 1547 as written; consider clarifications	TBD, Yes	TBD, Eval + Comm Test
4 (DUK-20)	4.10.3	Performance during entering service	Accept 1547 as written; consider clarifications	TBD, Yes	Eval + Comm Test
4 (DUK-21)	4.10.4	Synchronization	Accept 1547 as written; consider clarifications	No Reqmt	TBD, Eval + Comm Test
4 (DUK-22)	4.11.3	Paralleling device	Accept 1547 as written	No Reqmt	Type Test
5 (DUK-23)	4.9	Inadvertent energization of the Area EPS	Accept 1547 as written	No Reqmt	Eval + Comm Test
5 (DUK-24)	6.3	Area EPS reclosing coordination	Accept 1547 as written; consider clarifications; part of ongoing study	No Reqmt	Eval.
5 (DUK-25)	6.2	Area EPS faults and open phase conditions	Accept 1547 as written; consider clarifications; part of ongoing study	TBD	Eval + Comm Test
5 (DUK-26)	4.12	Integration with Area EPS grounding	Accept 1547 with clarifications	No Reqmt	Eval.
5 (DUK-27)	4.7	Prioritization of DER responses	Accept 1547 as written	No Reqmt	TBD, Eval + Comm Test
5 (DUK-28)	4.8	Isolation device	Accept 1547 as written	No Reqmt	Eval + Comm Test
5 (DUK-29)	4.11.1	Protection from electromagnetic interference	Accept 1547 as written	No Reqmt	Type Test
5 (DUK-30)	4.11.2	Surge withstand performance	Accept 1547 as written	No Reqmt	Type Test
5 (DUK-31)	4.6.3	Execution of mode or parameter changes	Accept 1547 as written	TBD, Yes	TBD, Eval + Comm Test
- (DUK-101)	9	Secondary network	Duke does not currently have these	No Reqmt	-
- (DUK-102)	11.4	Fault current characterization	TBD	No Reqmt	-

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
- (DUK-103)	8.1	Unintentional islanding	TBD	Yes	-
- (DUK-104)	8.2	Intentional islanding	TBD	Yes	-
- (DUK-105)	11	Test and verification	TBD	-	-
- (DUK-106)	10.2	Monitoring, control, and information exchange requirements	TBD	Yes	-
- (DUK-107)	10.5	Monitoring information	TBD	Yes	-
- (DUK-108)	6.4.2.5	Ride-through of consecutive voltage disturbances	TBD	No Reqmt	-
- (DUK-109)	6.4.2.6	Dynamic voltage support	TBD	No Reqmt	-
- (DUK-110)	6.5.2.8	Inertial response	TBD	No Reqmt	-
- (DUK-111)	10.1	Interoperability requirements	TBD	Yes	-
- (DUK-112)	10.3	Nameplate Information	TBD	Yes	-
- (DUK-113)	10.4	Configuration information	TBD	Yes	-
- (DUK-114)	10.6	Management information	TBD	Yes	-
- (DUK-115)	10.7	Communication protocol requirements	TBD	Yes	-
- (DUK-116)	10.8	Communication performance requirements	TBD	Yes	-
- (DUK-117)	10.9	Cyber security requirements	TBD	Yes	-
- (DUK-118)	7.3	Limitation of current distortion	TBD	TBD	-
- (DUK-119)	4.13	Exemptions for Emergency Systems and Standby DER	TBD	TBD	-
- (DUK-120)	6.4.2.7	Restore output with voltage ride-through	TBD	No Reqmt	0

1

LOGISTICS OF IMPLEMENTING OF IEEE 1547-2018

After the technical aspects of each Standard section are understood, Duke Energy can then determine the necessary changes to implement that section. This could vary from taking no action, to updating documentation, to changing work, study, and operational practices. Additionally, a consequence of more inverter functions will be the necessary increase in interoperability requirements as well as DER equipment and DER system verification and testing to confirm design and functional requirements. There are many aspects to consider before implementing each 1547 section. Because the actions to implement each section can vary widely, the implementation will be addressed in each section rather than as a whole for the entire Standard.

It is understood that many of the functions will not be available until IEEE 1547-2018 certified inverters are tested and available to the market. At that time, Duke Energy shall require all inverters to be IEEE 1547-2018 certified. All functions and requirements may not be applicable or implemented at the time the inverters become certified or that Duke Energy requires the certification. Prior to requiring IEEE 1547-2018, Duke Energy and the DER Owner for inverters certified to IEEE 1547a-2014 or UL 1741 SA may mutually agree to implement those available functions as needed.

PLANT REQUIREMENTS

Guidelines must consider how all sections may apply if implemented on a plant-scale with a power plant controller rather than at the individual inverter units. There may need to be some tests for verification that the plant controller performs the intended functions and that the underlying inverters to not behave contrary to the plant controller configuration or commands.

Note that in the following part of this document, the title of each section is the IEEE 1547-2018 section or subsection number and title.

SECTION 1.4 – GENERAL REMARKS AND LIMITATIONS

Duke Energy accepts the scope of the Standard as specified in this section. For UDER, the single point of common coupling (PCC) is located at the boundary between the utility electric power system (EPS) and the local EPS or DER EPS.

The technical specifications and requirements for some performance categories are specified by general technology-neutral categories. For categories related to reactive power capability and voltage regulation performance requirements, Duke Energy requires the following normal performance category:

Voltage and Reactive Power Category B

For categories related to response to Area EPS abnormal conditions, Duke Energy requires the following abnormal operating performance categories:

Synchronous generation	Category I
Induction generation	Mutual agreement
Inverter-based generation	Category III*
Inverter-based storage	Category III*

This section shall be applicable once 1547-2018 inverters are certified and required or if by mutual agreement between Duke Energy and the DER Owner for inverters certified to IEEE 1547a-2014 or UL 1741 SA.

* Final determination for the Category has not been made. More analysis is required and included as part of a study conducted jointly between the Duke Protection and Transmission Planning groups. This work includes a significant effort to model the system, perform iterative studies, and perform research. The main focus is on Category II and that is expected to be the minimum requirement for IBR. With the amendment to IEEE 1547a-2020 approved and many utilities standardizing on Category III, that is the most likely selection.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Independent laboratory certifications that attest to the normal and abnormal categories shall satisfy verification for this requirement.

Implementation of this section requires publishing the final position and integrating verification requirements into the overall commissioning test program.

SECTION 4.2 – REFERENCE POINTS OF APPLICABILITY (RPA)

Duke Energy requires the RPA for all performance requirements for UDER to be the PCC (point of common coupling), which is also known as the point of delivery or change of ownership point on the medium voltage side of the DER transformer(s). The RPA for net meter installations is the PoC (point of connection) at the inverter terminals.

Pending analysis: The expectation is that Duke can accept the Standard as written, but Duke must still determine if there are any applicable exceptions or clarifications needed given this portion of section 4.2:

> Alternatively, for Local EPSs where zero sequence continuity[27] between the PCC and PoC is maintained and either of the following conditions apply, the RPA for performance requirements of this standard may be the *point of DER connection* (PoC), or by mutual agreement between the *Area EPS* operator and the *DER operator*, at any point between, or including, the PoC and PCC:
>
> a) Aggregate DER nameplate rating of equal to or less than 500 kVA, *or*
>
> b) Annual average load demand[28] of greater than 10% of the aggregate DER nameplate rating, and where the Local EPS is not capable of, or is prevented from, exporting more than 500 kVA for longer than 30 s.
>
> For all other Local EPSs meeting either of the conditions a) or b) above but not meeting the requirement for zero sequence continuity, the RPA for performance requirements other than the response to *Area EPS* abnormal conditions specified in 6.2 and 6.4 shall be the PoC, or by mutual agreement between the *Area EPS operator* and the *DER operator*, at any point between, or including, the PoC and PCC. The RPA for performance requirements of 6.2 and 6.4 shall be a point between, or including, the PoC and PCC that is appropriate to detect the abnormal voltage conditions.[29, 30]
>
> Where the RPA is not at the PCC, any equipment or devices in the Local EPS between the RPA and the PCC shall not preclude the DER from meeting the disturbance ride-through requirements specified in 6.4.2 and 6.5.2.[31]
>
> For Local EPS where aggregate DER nameplate rating is greater than 500 kVA, and annual average load demand[28] is greater than 10% of the aggregate DER nameplate rating, and the Local EPS is capable of, and is not prevented from, exporting more than 500 kVA for longer than 30 s, the RPA shall be the PCC and

The final position must consider the variety of RDER and UDER interconnections and identify the RPA for each. In practice, the interconnections have been very straightforward. The default RPA is the PCC. Zero sequence continuity is not a factor for UDER, so the RPA for UDER is the PCC (point of common coupling at the utility interconnection point). The RPA for net meter installations must consider a variety of conditions, as noted in the decision trees, H.1 and H.2. Note that Section 4.12 also addresses grounding and zero sequence continuity.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke will to review DER design documents to confirm the location of the RPA is correct.

Implementation of this section requires publishing the final technical position.

SECTION 4.3 – APPLICABLE VOLTAGES

Duke Energy will consider if there is a need to clarify any technical points for the final version of the guideline, but the expectation is that the section is implemented as written. The expected outcome is that RDER parameters shall be monitored at the inverter terminals and UDER parameters shall be monitored at the EPS voltage level and used for inverter functions.

Interoperability requirements: Applicable voltages are provided to the local DER interface with Duke Energy.

Verification and test requirements: To be determined.

The applicable voltage should be identified in the interconnection process. Duke plans to review design document to verify the DER meet this requirement.

Implementation of this section requires publishing the final position, applying the interoperability functionality in the local interface, and integrating verification requirements into the overall commissioning test program.

SECTION 4.5 – CEASE TO ENERGIZE PERFORMANCE REQUIREMENT

Duke Energy requires cease to energize capability (not delivering power during steady-state or transient conditions) in accordance with the Standard.

A DER can be directed to cease to energize and trip by changing the Permit service setting to "disabled" as described in IEEE 1547 subsection 4.10.3.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke plans to review design document and equipment specification to identify the interconnection device that provides the cease-to-energize function. The existing inspection and commissioning process tests to verify the device meets the performance requirement.

This section is ready to be implemented.

SECTION 4.6 – CONTROL CAPABILITY REQUIREMENTS

Duke Energy will consider if there is a need to clarify any technical points for the final version of the guideline, but the expectation is that the capabilities in the following sections will be adopted as written.

Duke accepts the capabilities in the following sections as written:

4.6.1 Capability to disable permit service
4.6.2 Capability to limit active power
4.6.3 Execution of mode or parameter changes

This section of the Standard applies to all DER 250 kW or greater or DER with a local DER communication interface.

For UDER, Duke Energy is still considering implementing the permit service at the inverter or disconnecting at the local EPS.

Application to RDER has not been assessed.

Note that 4.6.2 is essentially part of the system impact study (SIS) process now because the maximum active power capacity (import or export) is often calculated during the SIS if the requested DER capacity is not possible without upgrades. The Standard defines the active power limit as a percentage of the Nameplate Active Power Rating. Duke interprets the referenced rating as the Nameplate Active Power Rating at unity power factor. Consider too that the active power limit is manually set and Duke does not have the capabilities to adjust the limit based on time of day, load, or other variables.

Duke does not plan to implement real-time control during the initial implementation of the Standard. Significant technical studies are required to address concerns and consider remote real-time control of the active power limit. However, it is reasonable to make provision for this potential capability when designing the monitoring and control capabilities of the communication interface.

Interoperability requirements: The present automation controller implementation uses an Analog Output sent via SCADA to control active power.

Verification and test requirements: Duke will review UL certification tests, type tests, design documents, and equipment specifications to identify the capability of the DER to meet this performance requirement. Duke's current policy requires a utility owned interconnection recloser for UDER >= 1MW. In this case the permit service is implemented by controlling the utility owned recloser. For DER >= 250kW and <1MW, Duke allows the option of installing the small DG interface instead of the utility owned recloser. In this case, the permit service is implemented at the DER unit through the small DG interface.

Implementation of this section requires publishing the final technical position.

SECTION 4.7 – PRIORITIZATION OF DER RESPONSES

Duke Energy expects IEEE 1547-2018 compliant inverters to meet all prioritization requirements of this section of the Standard.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke plans to review UL certification testing, type tests results, and design documents to evaluate if a DER can meet this requirement.

This section is ready to be implemented.

SECTION 4.8 – ISOLATION DEVICE

Duke Energy requires isolation devices per the Interconnection Agreement, Method of Service Guidelines, and other interconnection documents. This is a current requirement that is unchanged by IEEE 1547-2018.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Existing site evaluation and inspection shall satisfy verification for this requirement.

This section is ready to be implemented.

SECTION 4.9 – INADVERTENT ENERGIZATION OF THE AREA EPS

Duke Energy requires DER not to energize the utility EPS when the utility EPS is de-energized. When there is a planned and designed intentional island, per Section 8.2 Intentional Islanding, that configuration is not considered inadvertent.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke will only accept type-tested DER for small scale installations like RDER. For UDER, the existing inspection and commissioning process covers this requirement.

This section is ready to be implemented.

SECTION 4.10 – ENTER SERVICE

Duke Energy requires the DER to meet the requirements of all the following subsections:

4.10.2 Enter service criteria
4.10.3 Performance during entering service
4.10.4 Synchronization

> Duke must still determine the enter service criteria and enter service time delays. Note that while the Standard mentions Range B of ANSI C84.1, that voltage is at the service level (low side of the service transformer) and not at the primary side. Therefore, the settings in the Standard would be more relevant to RDER than UDER that has the RPA and PCC at the primary side of the DER transformer. The RDER values are common in the industry and are Standard defaults.

When entering service, the DER shall not energize the Area EPS until the following conditions are met:

Enter service value	Parameter Label	RDER setting (Service tx sec)	UDER setting (DER tx pri)
Minimum Voltage	ES_V_LOW	≥ 0.917 p.u.	≥ p.u.
Maximum Voltage	ES_V_HIGH	≤ 1.05 p.u.	≤ p.u.
Minimum Frequency	ES_F_LOW	≥ 59.5 p.u.	≥ p.u.
Maximum Frequency	ES_F_HIGH	≤ 60.1 p.u.	≤ p.u.

Note: The parameter labels are based on the publicly available EPRI technical update document number 3002020201, "*Common File Format for Distributed Energy Resources Settings Exchange and Storage.*"

> The final UDER settings are still under evaluation. Duke will compare the final voltage trip and ride through settings for UDER with the Standard default settings. Assuming they are compatible, UDER will adopt the same Standard default values.

The DER shall not enter service or ramp faster than the times stated below. A randomized time delay is optional and not currently used within the Duke system. As noted in the standard, DER increasing active power steps greater than 20% of Nameplate Active Power rating shall require approval during the system interconnection study process.

Time Delay	**Parameter Label**	**RDER setting (seconds)**	**UDER setting (seconds)**
Enter Service Delay	ES_DELAY	300	300
Enter Service Ramp Period	ES_RAMP_RATE	300	300
Enter service randomized delay	ES_RANDOMIZED_DELAY	Off	Off

While the active power is ramping during the enter service period, the reactive power shall follow the configured mode and settings.

When connected in parallel with the Area EPS, energy storage DER (ESS) active power rate of change is dependent on the Configuration Active Power Rating per the table below:

Rate of Change Duration	**Parameter Label**		**RDER setting (seconds)**	**UDER setting (seconds)**
ESS ≤ 1 MW	None		2	n/a
ESS > 1 MW	None		n/a	ESS MW rating / (2 MW/sec)

Interoperability requirements: To be determined.

> Duke will evaluate if there is value in monitoring the enter service settings.

Verification and test requirements: For 4.10.2 and 4.10.3, Duke plans to verify the enter service and return to service settings in the field. The existing inspection and commissioning process tests to verify DER meets this requirement. For 4.10.4, Duke plans to review UL certification tests, type tests, and design documents to evaluate DER's synchronization capability meeting this requirement. The on-off test during commissioning will field verify DER's synchronization capability.

Implementation of this section requires publishing the final technical position and applying the interoperability functionality in the local interface.

SECTION 4.11 – INTERCONNECT INTEGRITY

Duke Energy requires the DER to meet the requirements of all the following subsections:

- 4.11.1 Protection from electromagnetic interference
- 4.11.2 Surge withstand performance
- 4.11.3 Paralleling device

Duke Energy does not have additional clarifications of these subsections.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: They standard type-testing is satisfactory for Duke.

This section is ready to be implemented.

SECTION 4.12 – INTEGRATION WITH AREA EPS GROUNDING

Duke accepts the Standard; that the grounding scheme of the DER interconnection shall be coordinated with the ground fault protection of the Area EPS. Duke's system is multi-grounded and the DER facilities and design must be compatible with the EPS. Each interconnection is reviewed for ground fault protection and for limiting the potential for creating over-voltages on the Area EPS.

Approved distribution connected utility scale DER transformer winding configurations are listed below. Therefore, configurations that are not listed are not approved. It is possible for an IC to submit another winding configuration, however the technical review will significantly delay evaluation of the IR.

Primary Winding Type (HV)	Secondary Winding Type (LV)	Zero Seq Maintained PCC to POC	Allowed for DER Interconnection	
			Inverter	Rotating
Wye-grounded	Wye-grounded	Yes, (w/4-wire LV)	Yes	Yes
Wye-grounded	Wye	No	Yes	No
Wye-grounded	Delta	No	No	Yes

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke plans to review the design document to evaluate if a DER can meets this requirement. The existing inspection and commissioning test process will cover this.

This section is ready to be implemented.

SECTION 5.2 – REACTIVE POWER CAPABILITY OF THE DER

Whether or not reactive power capability or voltage control is initially used for the DER, each DER shall submit the required reactive power capability information. This provides the information when it is most readily available and can be recorded in the event that it is needed later.

For categories related to reactive power capability and voltage regulation performance requirements, Duke Energy plans to require the following performance category:

Voltage and Reactive Power Category B

Category B requires a DER reactive power injection capability (lagging) of 44% of nameplate apparent power rating and 44% absorption capability (leading) of nameplate apparent power rating as defined in the Standard. As a good practice, Duke recommends that all facilities be designed to operate at these pf ratings should the situation arise over the life of the facility that the facility would want this capability.

Because the capability curve limit must be satisfied, the vector sum of the active and reactive powers must not exceed the apparent power capability[2]. The reactive capability shall be provided on an inverter capability curve (P-Q graph) and shall be based at the rated voltage of the device (1 pu) and an ambient temperature of 35° C. The DER may choose to submit reactive capability data on a higher ambient temperature basis, however that data will still be applied as the 35° C capability (Duke cannot temperature adjust manufacturer data).

Because operating points on the chart can be difficult to accurately determine, it is recommended that the DER provide the numerical data that defines critical points on the capability curve. Those points include the Nameplate and Configuration apparent, active, and reactive power ratings at the leading, lagging, and unity power factors.

Some facilities have operational, design, or other limitations that prevent utilization of the full reactive capability of the device(s). If that is the case, the DER shall specify any factors that limit or de-rate the output of the generator (e.g., collector system voltage limits, auxiliary voltage limits, net meter load voltage limits, current limits, and specific ambient temperature conditions). If no limitations are submitted, then Duke will consider that the facility has no reactive capability limitations. Duke recommends submittal of a facility capability curve that includes any limitations.

Supplemental Devices

If the DER includes supplemental devices, capability data must be provided for each device at rated voltage of the device and an ambient temperature of 35° C. Subject to the same conditions above, the DER may elect to submit data at a higher ambient temperature. For a dynamic device, capable of varying output magnitude, a capability curve must be provided with a brief written description and an acceptable power flow model of the device. If the supplemental device is static (i.e. a fixed capability), then a curve is not required, but the appropriate capability data must be provided and the type of device identified. Additionally, if there are multiple devices that form the complete DER, a composite capability curve that includes all sources, loads, and supplemental devices shall be provided.

[2] See the EPRI document "Understanding Watt and Var Relationships in Smart Inverters", 3002015102

Again, any limitations that prevent the full reactive capability of the device(s) to be utilized shall be specified and Duke recommends submittal of a facility capability curve that includes the limitations.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke plans to evaluate design documents and equipment specifications to determine reactive power capability. A field test may be required for DER to prove its reactive power capability. Duke expects to follow the commissioning tests requirements in IEEE 1547.1 to cover this topic.

Implementation of this section requires publishing the final position and integrating verification requirements into the overall commissioning test program.

SECTION 5.3 – VOLTAGE AND REACTIVE POWER CONTROL

The Standard lists several forms of reactive power control:

- Constant power factor mode
- Constant reactive power mode
- Voltage-reactive power mode
- Active power-reactive power mode

Constant reactive power is not thought to be a particularly useful control mode. Constant power factor is the broad category of control that includes unity power factor, which can be useful, but is limited by operating at a control point that is not based on feeder conditions. Duke is in the process of performing studies that will focus on voltage-reactive power mode and active power-reactive power mode for UDER. The Duke study will evaluate the application and consequences of these functions.

Part of the study effort is to determine if voltage regulation functions should be activated and how they should be configured. Before using these functions on a widespread basis, Duke Energy will evaluate the system impacts, identify any unanticipated effects, and then assess the control modes and settings. Because the impact of UDER reactive injection can be large, Duke limits the reactive capability that can be used for reactive power control to 0.95 power factor.

In North and South Carolina utility scale solar, UDER, is the majority of the solar capacity installed. Therefore, study efforts will focus on that type of facility. In due time, there should be some consideration for residential-scale inverters as well. The reactive control method and settings should consider existing operational requirements as well as mitigation of the high voltages that can occur with the addition of DER. No change can be made on one part of the system that does not affect another part. Therefore, the study will also consider the magnitude of influence the inverter has on voltage, reactive power flow impacts, remediation of impacts, and controlling the impact on the transmission system. Distribution Providers must comply with agreements and requirements of the transmission entities. As such, an evaluation of transmission impacts is important.

Significant technical studies are required to evaluate these functions and analyze the consequences. The studies began at the end of 2019 and will continue in 2021. This will continue to be an agenda item for the TSRG meetings will focus on the most useful control modes and settings that are applied locally in the inverter and are autonomous.

Duke Energy has reviewed and considered all TSRG and submitted comments up to the date of this revision.

Interoperability requirements: To be determined.

Even with autonomous operation there will be some requirements to communicate the VAR priority mode and reactive power mode to Duke, and possibly other information. Because those requirements are not known at this time, Duke must perform additional analysis and interface testing for autonomous operation. For example, some DER require a 0-100% setpoint while others require an actual value in kVAR. In the future, there may be value in providing the necessary controls for remote utility control. That is second priority to autonomous operation, but that would require even more controls and monitoring. While priority can be enabled/disabled with a Binary Output, separate Analog Outputs must be used to set the individual control setpoints for each mode.

At this time, Duke does not have the capability to remotely control or manage distribution connected reactive power resources. However, there is some expectation that functionality may be necessary or available within the life of the DER. Facilities may want to make provision for interoperability capabilities that include both autonomous operation as well as remote control and adjustment of setpoints.

Verification and test requirements: To verify DER compliance to this requirement, Duke will require evaluation of the volt-var settings and field settings verification. Due to complication of performing voltage tests in the field, Duke does not plan to require field commissioning test on this topic. Operational data may be required to evaluate the DER's performance meeting this requirement.

Additional analysis must be performed before finalizing the Verification and test requirements.

Implementation of this section requires publishing the final position, applying the interoperability functionality in the local interface, and integrating verification requirements into the overall commissioning test program.

SECTION 5.4 – VOLTAGE AND ACTIVE POWER CONTROL

The main requirement here involves subsection 5.4.2, Voltage-active power mode. The voltage-active power mode serves as a backup to voltage control. Should an unexpected high voltage condition arise, or the voltage cannot be controlled by the local reactive resources, the voltage-active power control will reduce the DER active power to assist with voltage control

The settings and specifications for voltage-active power control are included with the study discussed for Section 5.3.

Interoperability requirements: To be determined.

Even with autonomous operation there will be some requirements to communicate the mode and possibly other information. Because those requirements are not known at this time, Duke must perform additional analysis and interface testing for autonomous operation.

Duke has the initial I/O points for active power control. The SCADA interface required and operations and functional requirements are still to be determined.

In the future, there may be value in providing the necessary controls for remote utility control. That is second priority to autonomous operation, but that would require even more controls and monitoring. While the mode can be enabled/disabled with a Binary Output, separate Analog Outputs must be used to set the individual control setpoints.

Verification and test requirements: To verify DER compliance to this requirement, Duke will require evaluation of the volt-watt settings and field settings verification. Due to complication of performing voltage tests in the field, Duke does not plan to require field commissioning test on this topic. Operational data may be required to evaluate the DER's performance meeting this requirement.

Additional analysis must be performed before finalizing the Verification and test requirements.

Implementation of this section requires publishing the final position, applying the interoperability functionality in the local interface, and integrating verification requirements into the overall commissioning test program.

SECTION 6.2 – AREA EPS FAULTS AND OPEN PHASE CONDITIONS

Duke Energy has not determined the guidelines for this section. While the Standard may be accepted as written, there may need to be clarifications.

This is a sub-task of an ongoing project involving the Protection and Transmission Planning groups. There is an enormous effort to model the system, perform iterative studies, perform the research, and evaluate protection settings. Duke Energy is working to determine the best DER recloser protection elements to optimize protection and ride-through performance and establish the abnormal operating performance Categories.

Interoperability requirements: To be determined.

Duke Energy must evaluate if there are any interoperability requirements for this section.

Verification and test requirements: The existing inspection and commissioning process covers the verification of this requirement. Duke plans to continue the practice and refine the process as necessary following the commissioning test requirements in IEEE 1547.1.

Implementation of this section requires publishing the final position, applying the interoperability functionality in the local interface.

SECTION 6.3 – AREA EPS RECLOSING COORDINATION

Duke Energy has not determined the guidelines for this section. While the Standard may be accepted as written, there may need to be clarifications.

This is a sub-task of an ongoing project involving the Protection and Transmission Planning groups. There is an enormous effort to model the system, perform iterative studies, perform the research, and evaluate protection settings. Duke Energy is working to determine the best DER recloser protection elements to optimize protection and ride-through performance and establish the abnormal operating performance Categories.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: For large scale DER that is equipped with a Duke PCC recloser, such coordination will be considered under the Duke Energy DER Enterprise Standards. For other DER, Duke will follow the commissioning tests requirements in IEEE 1547.1.

Implementation of this section requires publishing the final position.

SECTION 6.4.1 – MANDATORY VOLTAGE TRIPPING REQUIREMENTS

Duke Energy has not determined the guidelines for this section.

This is a sub-task of an ongoing project involving the Protection and Transmission Planning groups. There is an enormous effort to model the system, perform iterative studies, perform the research, and evaluate protection settings. Duke Energy is working to determine the best DER recloser protection elements to optimize protection and ride-through performance and establish the abnormal operating performance Categories.

Consensus was reached with Transmission System Planning and Operations for POI Recloser voltage and frequency settings and time delays that provide adequate ride-through for BES events. The team is still reviewing the impact to system protection with the proposed settings.

Interoperability requirements: To be determined.

It is expected that these values will be set and not changed remotely, however this position must be evaluated by Duke. Because these are critical protection setpoints, remote visibility of the setting would be a beneficial capability. Because requirements are not known at this time, Duke must perform additional analysis before establishing interoperability requirements. Note that this setting is incorporated in SUNSPEC MODBUS.

Verification and test requirements: The existing inspection and commissioning process covers the voltage trip settings field verification and Duke plans to continue that practice. Due to complication of performing abnormal voltage tests in the field, Duke plans to perform design evaluation and installation evaluation for the purpose of evaluating conformance of the DER, and currently does not plan to require field commissioning tests on this topic. Operational data collection after a DER or system event may be required to validate proper DER operation. IEEE 1547.1-2020 suggests signal injection test method may be considered if the DER has the provision for this method. Adjustment of the shall-trip settings may be made if verification of the mandatory trip function is required.

Implementation of this section requires publishing the final position and applying the interoperability functionality in the local interface.

SECTION 6.4.2 – VOLTAGE DISTURBANCE RIDE-THROUGH REQUIREMENTS

Duke Energy has not determined the guidelines for this section, but these requirements are being developed concurrently with Section 6.4.1 – Mandatory voltage tripping requirements.

See Section 1.4 for the abnormal performance category.

Interoperability requirements: To be determined.

It is expected that these values will be set and not changed remotely, however this position must be evaluated by Duke. Because these are critical protection setpoints, remote visibility of the setting would be a beneficial capability. Because requirements are not known at this time, Duke must perform additional analysis before establishing interoperability requirements. Note that this setting is incorporated in SUNSPEC MODBUS.

Verification and test requirements: To verify DER compliance, Duke will require evaluation of the DER ride-through settings and field setting verification. Due to complication of performing abnormal voltage tests in the field, Duke plans to perform design evaluation and installation evaluation for the purpose of evaluating conformance of the DER, and currently does not plan to require field commissioning tests on this topic. Operational data collection after a DER or system event may be required to validate proper DER operation. IEEE 1547.1-2020 suggests signal injection test method may be considered if the DER has the provision for this method. Adjustment of the shall-trip settings may be made if verification of the mandatory trip function is required.

Implementation of this section requires publishing the final position and applying the interoperability functionality in the local interface.

6.4.2.6 Dynamic voltage support

At least one Duke region requires dynamic reactive compensation for transmission connected DER. Application for the distribution system is still under evaluation.

SECTION 6.5.1 – MANDATORY FREQUENCY TRIPPING REQUIREMENTS

> Duke Energy has not determined the guidelines for this section, but these requirements are being developed concurrently with Section 6.4.1 – Mandatory voltage tripping requirements.

Interoperability requirements: To be determined.

> It is expected that these values will be set and not changed remotely, however this position must be evaluated by Duke. Because these are critical protection setpoints, remote visibility of the setting would be a beneficial capability. Because requirements are not known at this time, Duke must perform additional analysis before establishing interoperability requirements. Note that this setting is incorporated in SUNSPEC MODBUS.

Verification and test requirements: The existing inspection and commissioning process covers the frequency trip settings field verification and Duke plans to continue that practice. Due to complication of performing abnormal frequency tests in the field, Duke plans to perform design evaluation and installation evaluation for the purpose of evaluating conformance of the DER, and currently does not plan to require field commissioning tests on this topic. Operational data collection after a DER or system event may be required to validate proper DER operation. IEEE 1547.1-2020 suggests signal injection test method may be considered if the DER has the provision for this method. Adjustment of the shall-trip settings may be made if verification of the mandatory trip function is required.

Implementation of this section requires publishing the final position and applying the interoperability functionality in the local interface.

SECTION 6.5.2 – FREQUENCY DISTURBANCE RIDE-THROUGH REQUIREMENTS

For sections 6.5.2.1 through 6.5.2.4, concerning frequency ride-through:

> Duke Energy has not determined the guidelines for this section, but these requirements are being developed concurrently with Section 6.4.1 – Mandatory voltage tripping requirements.

The Standard also includes several subsections related to frequency. Although Duke Energy considers these requirements mainly as functional specifications for the inverter, Duke Energy does have additional requirements or clarifications.

6.5.2.5 Rate of change of frequency (ROCOF)
UL certification testing should verify the inverter will ride through a 3 Hz/s excursion. That being the case, no generator on the utility system shall intentionally trip for ROCOF using protective relaying or DER

controller functions. DER tripping for ROCOF, if available, should be off or disabled. The DER shall certify that protective relay settings & controller settings do not intentionally trip for ROCOF.

This function, either at the inverter or the utility PCC recloser, is still under evaluation. Duke anticipates adopting the 1547 requirements if that is supported by the ongoing project.

6.5.2.6 Voltage phase angle changes ride-through

This function, either at the inverter or the utility PCC recloser, is still under evaluation. Duke anticipates adopting the 1547 requirements if that is supported by the ongoing project.

6.5.2.7 Frequency-droop (frequency-power) capability

This function is still under evaluation. Per Standard table 22, a specification of the droop, deadband, and associated parameters is required for Category III.

6.5.2.8 Inertial response

Duke Energy has not determined the guidelines for this subsection. This capability is not required by the Standard but is permitted.

Interoperability requirements: To be determined.

It is expected that these values for Section 6.5.2 will be set and not changed remotely, however this position must be evaluated by Duke. Because these are critical protection setpoints, remote visibility of the setting would be a beneficial capability. Because requirements are not known at this time, Duke must perform additional analysis before establishing interoperability requirements. Note that this setting is incorporated in SUNSPEC MODBUS.

Verification and test requirements: To verify DER compliance, Duke will require evaluation of the DER ride-through settings and field setting verification. Due to complication of performing abnormal frequency tests in the field, Duke plans to perform design evaluation and installation evaluation for the purpose of evaluating conformance of the DER, and currently does not plan to require field commissioning tests on this topic. Operational data collection after a DER or system event may be required to validate proper DER operation. IEEE 1547.1-2020 suggests signal injection test method may be considered if the DER has the provision for this method. Adjustment of the shall-trip settings may be made if verification of the mandatory trip function is required.

Implementation of this section requires publishing the final position and applying the interoperability functionality in the local interface.

SECTION 7.2.2 – RAPID VOLTAGE CHANGES

Duke has an existing process that is part of the system impact study to assess the risk of Rapid Voltage Changes (RVC) and require mitigation if necessary. Duke considers that the existing RVC criteria is consistent with the Standard and does not plan further evaluation.

Interoperability requirements: To be determined.

Based on the type of inrush mitigation used, there could be some status points that are useful for situational awareness. Because requirements are not known at this time, Duke must perform additional analysis before establishing interoperability requirements.

Verification and test requirements: The installation evaluation is currently included in the scope of Duke's interconnection inspection process, but the performance of the mitigation is not currently tested. A power quality meter is required for the field tests. Duke plans to evaluate the DER RVC impact and mitigation performance by reviewing the data collected during the commissioning test (such as cease-to-energize test). Duke will develop a test procedure and criteria to evaluate the performance of a RVC mitigation solution as part of the commissioning tests.

Implementation of this section requires applying the interoperability functionality in the local interface and integrating verification requirements into the overall commissioning test program.

SECTION 7.2.3 – FLICKER

Duke Energy adopts these requirements as written in the Standard. Note that Duke also applies IEEE 1453 recommended practices.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke plans to review design document and equipment specification to evaluate the potential flicker cause DER. A power quality meter is required for the field tests. Duke plans to follow the commissioning tests requirements in IEEE 1547.1. Operational data collection after a DER or system event may be required to validate proper DER operation.

This section is ready to be implemented.

SECTION 7.3 – LIMITATION OF CURRENT DISTORTION

Duke Energy adopts these requirements as written in the Standard. The industry has found that the inverter designs are reaching and exceeding the harmonic monitoring capabilities of existing measurement devices. Therefore, Duke Energy requires the DER owner to mitigate all order harmonics to no greater than 0.3% if the harmonics affect other customers. Harmonic limits shall be aggregated and applied during the DER hours of operation.

Interoperability requirements: No specific requirements for this section. Installation of a power quality meter is already part of the required design for DER 1 MW and greater.

Verification and test requirements: Duke plans to follow the commissioning tests requirements in IEEE 1547.1.

This section is ready to be implemented.

SECTION 7.4.1 – LIMITATION OF OVERVOLTAGE OVER ONE FUNDAMENTAL FREQUENCY PERIOD

Duke Energy adopts these requirements as written in the Standard.

Part of 7.4.1 is based on the inverter design and operation and part is based on the specific design of the interconnection and the Area EPS itself. The ability of the inverter to detect and limit overvoltage will be verified by UL certification testing. However, the DER facility must still be analyzed during system impact study to verify the impact of the combined inverter and Area EPS is below the limits of the Standard. The limits defined in parts a) and b) must be verified by power system study.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke plans to rely on UL certification testing, review type tests results, and examine design documents to evaluate the potential overvoltage contribution from DER. Duke plans to develop a test procedure and criteria for transient overvoltage during the commissioning test. A power quality meter is required for the field tests. Duke plans to follow the commissioning tests requirements in IEEE 1547.1.

This section is ready to be implemented.

SECTION 7.4.2 – LIMITATION OF CUMULATIVE INSTANTANEOUS OVERVOLTAGE

Duke Energy has not determined the guidelines for this section. More industry experience or analysis could be essential to address this issue. Duke does not plan to implement this section until IEEE 1547.1 is revised and UL 1741 certification tests include this verification. At that time, Duke expects to adopt these requirements as written in the Standard.

Interoperability requirements: No specific requirements for this section.

Verification and test requirements: Duke plans to review type tests results and design documents to evaluate the potential overvoltage contribution from DER. Duke plans to develop a test procedure and criteria for transient overvoltage during the commissioning test. A power quality meter is required for the field tests. Duke plans to follow the commissioning tests requirements in IEEE 1547.1.

Implementation of this section requires publishing the final technical position.

SECTION 10.3, 10.4 – NAMEPLATE AND CONFIGURATION INFORMATION

These sections address the two broad types of information available through the local DER communication interface. The following terms are listed in decreasing order of magnitude. The value of each parameter in the list is greater than or equal to the value of the parameter below it:

Nameplate Apparent Power Maximum Rating
Configuration Apparent Power Maximum Rating
Nameplate Active Power Rating (unity power factor)
Configuration Active Power Rating (unity power factor)

> The list above does not address all the terms in the table. Such a specification is not necessary of every term, but helpful to clarify for some. Duke will consider addressing other terms as needed. Consequently, operational limits and settings, such as the Active Power Limit, cannot be greater than the ratings (not applicable to abnormal or protection settings).

Ratings are considered a permanent characteristic of a device or a system and are characterized by:

- Rating is the full capacity of the equipment or system.
    - The rating is the most capacity the system is designed to provide
- Rating represents a continuous capacity. Operation at the Rating can continue for indefinitely long periods without exceeding design limits and without reducing the life or maintenance interval.
    - Also, there can be short-term ratings that are time limited. Operation within the parameter and time limit does not exceed design limits or negligibly reduce the life or maintenance interval.
- Rating is the base upon which other model, analysis, and inverter parameters are referenced.
- Ratings are a common way to identify and classify devices.

Limits are not included in these sections of the Standard. However, their relationship to and differences from ratings are important. Limits are adjustable, provide boundaries not to be exceeded, and are less than or equal to ratings. Limits are characterized by:

- Limits impose boundaries on device operation, often to restrict operation within ratings.
- Limits can be established or defined by contractual, system design, or physical equipment restrictions.
- Limits are set for a controlled variable and must not be exceeded (e.g. boundary condition).
- Limits are often stated as a percent of the rating (therefore necessitating a fixed rating value).

The Nameplate Active Power Rating is an important design parameter for the DER, but also as an important base parameter for modeling. The same for Nameplate Apparent Power Maximum Rating, for some equipment or models, parameters may be specified in terms of percent of Nameplate Apparent Power or Nameplate Active Power Rating. In cases where operation to the full Nameplate Active Power Rating is not acceptable for the application, then the Configuration Active Power Rating can be set to establish a lower rating. While the minimum of these two values sets the overall rating, it can be important to distinguish between these when it comes to equipment specifications and modeling.

UNADDRESSED REQUIREMENTS OF IEEE 1547-2018

The remaining IEEE 1547-2018 clauses and sections not discussed above will be undertaken following the completion of the higher priority topics. Concerning the clauses and sections not addressed in this document, Duke Energy expects that the DER shall conform to the Standard itself as written.

APPENDIX – IEEE 1547-2018 BENCHMARKING

Duke Energy requested that Navigant Consulting, Inc. to facilitate the stakeholder discussion at the January 2020 TSRG meeting and to perform benchmarking. The following table was developed by Navigant Consulting, Inc.

TABLE B.1. BENCHMARKING OF IEEE 1547-2018 FUNCTIONALITIES IMPLEMENTATION

IEEE 1547 Section	Topic	Duke Order (pre-stakeholder)	Minnesota/ Colorado (Xcel Energy)	Ameren / MISO
6.4.2	Voltage disturbance ride-through requirements	1	1	1
5.3	Voltage and reactive power control	1	1	1
6.5.2	Frequency disturbance ride-through requirements	2	1	1
6.4.1	Mandatory voltage tripping requirements (OV/UV)	1	1	2
5.4.2	Voltage-active power control	1	1	2
6.5.2.7	Frequency-droop (frequency-power) capability	2	1	2
6.5.1	Mandatory frequency tripping requirements (OF/UF)	2	1	2
5.2	Reactive power capability of the DER	1	1	
4.5	Cease to energize performance requirement [Reliability]	3	2	
4.6.1	Capability to disable permit service	3	2	
4.6.2	Capability to limit active power	3	2	
4.10.2	Enter service criteria	4	3	2
7.2.2	Power Quality, Rapid voltage change (RVC)	1	3	
4.10.3	Performance during entering service	4	3	
4.10.4	Synchronization	4	3	
4.2	Reference points of applicability (RPA) [Interconnection]	4	3	
6.5.2.5	Rate of change of frequency (ROCOF)	4	4	1
4.10	Enter service [Reliability] // 6.6 Return to service after trip	4	4	2
6.4.2.6	Dynamic voltage support		4	2
4.3	Applicable voltages [Manufacturer]	4	4	
4.11.3	Paralleling device	4	4	
6.2	Area EPS faults and open phase conditions [Reliability]		4	
6.3	Area EPS reclosing coordination [Reliability]		4	

IEEE 1547 Section	Topic	Duke Order (pre-stakeholder)	Minnesota/ Colorado (Xcel Energy)	Ameren / MISO
10.2	Monitoring, control, and information exchange requirements		4	
10.5	Monitoring information		4	
10.1	Interoperability requirements		4	
10.3	Nameplate Information		4	
10.4	Configuration information		4	
10.6	Management information		4	
10.7	Communication protocol requirements		4	
10.8	Communication performance requirements		4	
10.9	Cyber security requirements		4	
11	Test and verification		4	
8.2	Intentional islanding		4	
11.4	Fault current characterization		4	
9	Secondary network		4	
4.6.3	Execution of mode or parameter changes [Manufacturer]		4	
6.5.2.6	Voltage phase angle changes ride-through	2		1
6.4.2.5	Ride-through of consecutive voltage disturbances			1
7.2.3	Power Quality, Flicker	1		
7.4	Limitation of overvoltage contribution	1		
6.5.2.8	Inertial response			
7.3	Limitation of current distortion			
8.1	Unintentional islanding			
4.7	Prioritization of DER responses			
4.8	Isolation device [Interconnection]			
4.11.1	Protection from electromagnetic interference			
4.11.2	Surge withstand performance			
4.12	Integration with Area EPS grounding [Reliability]			
4.13	Exemptions for Emergency Systems and Standby DER			
4.9	Inadvertent energization of the Area EPS [Interconnection]			

1

ATTACHMENT B

Duke Energy Carolinas, LLC and Duke Energy Progress, LLC's Technical Standards Review Group Presentations *re:* Implementation of IEEE 1547-2018

Docket No. E-100, Sub 101
Docket No. E-100, Sub 101B

Action Plan to Implement 1547
January 21, 2020

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Action Plan to Implement 1547

Anthony C Williams, P.E.
Principal Engineer
DER Technical Standards

January 21, 2020

DUKE ENERGY®

Agenda

- How to prioritize or order IEEE 1547 requirements
  - Interconnection related
  - Priority and complexity
- Review Duke Evaluation of the order
- Conduct stakeholder process for implementing various aspects of the IEEE 1547-2018 standard
  - Stakeholder feedback and input
  - Poll

Note: North Carolina Commission tasked Duke to evaluate the costs and benefits of implementing various aspects of the IEEE 1547-2018 standard and file a report with the Commission by April 1, 2020

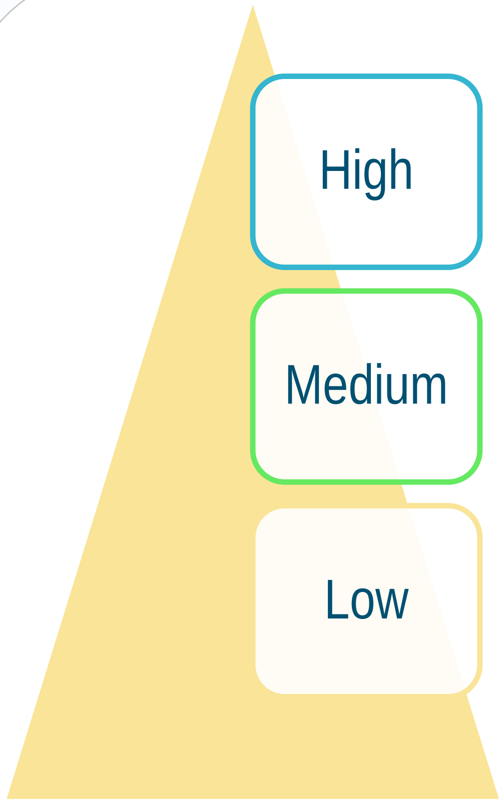
Ground Rules

- All Stakeholder Group meetings, webinars and information exchange are designed solely to provide an open forum or means for the expression of various points of view in compliance with antitrust laws.
- Under no circumstances shall Stakeholder Group activities be used as a means for competing companies to reach any understanding, expressed or implied, which tends to restrict competition, or in any way, to impair the ability of participating members to exercise independent business judgment regarding matters affecting competition or regulatory positions.
- Proprietary information shall not be disclosed by any participant during any group meetings. In addition, no information of a secret or proprietary nature shall be made available to Stakeholder Group members.
- All proprietary information which may nonetheless be publicly disclosed by any participant during any group meeting shall be deemed to have been disclosed on a non-confidential basis, without any restrictions on use by anyone, except that no valid copyright or patent right shall be deemed to have been waived by such disclosure.

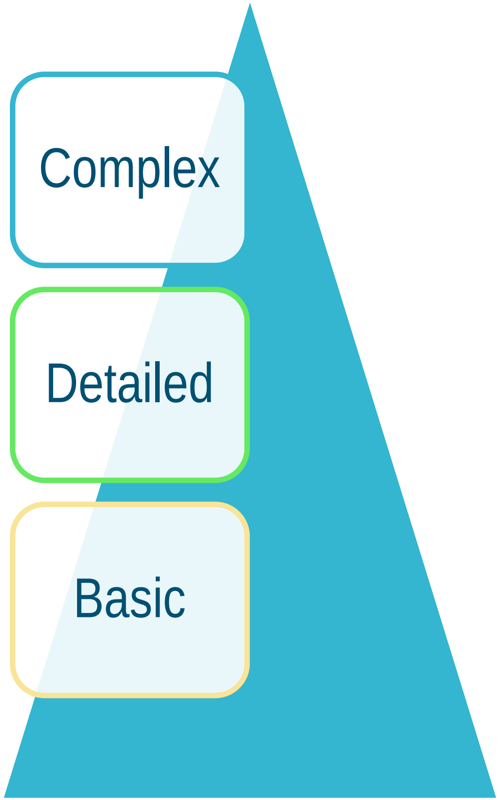
Logistics

- Today’s presentation will be distributed
- Clarifying questions will be answered during the presentation and stakeholder discussions at the end of the presentation
- Written feedback and comments will be solicited using comment form
- Comment form will be distributed along with presentation after the meeting
- Share the feedback form using email: Duke-IEEE1547@duke-energy.com for stakeholders to provide their written feedback

Priority and Complexity



1. Functions that enable higher penetrations of DER
2. Rank topics based on stakeholder preference
3. Note that there will be a need to spread the more complex functions over time



Interconnection Related Functions

- Past TSRG input -- Functions that enable higher penetrations of DER
- The following functions in 1547 improve the capability of DER to interconnect:
  - 5.2 Reactive power capability of the DER
  - 5.3 Voltage and reactive power control
    - 5.3.2 Constant power factor mode
    - 5.3.3 Voltage-reactive power mode
    - 5.3.4 Active power-reactive power mode
    - 5.3.5 Constant reactive power mode
  - 5.4 Voltage and active power control
    - 5.4.2 Voltage-active power mode
  - 4.6.2 Capability to limit active power

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Interconnection Function Status

- Active evaluations
  - Starting with 5.3 Voltage and reactive power control
    - By necessity then, 5.2 Reactive power capability of the DER
  - Secondary focus on 5.4 Voltage and active power control
- Future evaluation
  - 4.6.2 Capability to limit active power
    - In a way, done now by restricting kW at SIS
    - Performing this during real time operations is complex
      - Implementation would need considerable investigation
- Three of these four more important functions are in progress

IEEE 1547 Basic Functions and Requirements

- S4.1 – 4.6: General
  - 4.1 Introduction
  - 4.2 Reference points of applicability (RPA) [Interconnection]
  - 4.3 Applicable voltages [Manufacturer]
  - 4.4 Measurement accuracy [Manufacturer]
  - 4.5 Cease to energize performance requirement [Reliability]
  - 4.6 Control capability requirements
    - 4.6.1 Capability to disable permit service [Reliability]
    - 4.6.3 Execution of mode or parameter changes [Manufacturer]
- S4.8 – 4.10: General
  - 4.8 Isolation device [Interconnection]
  - 4.9 Inadvertent energization of the Area EPS [Interconnection]
  - 4.10 Enter service [Reliability]

IEEE 1547 Technical Functions and Requirements

- S6: Response to Area EPS abnormal conditions
  - 6.2 Area EPS faults and open phase conditions [Reliability]
  - 6.3 Area EPS reclosing coordination [Reliability]
  - 6.4 Voltage [Reliability]
    - 6.4.1 Mandatory voltage tripping requirements
    - 6.4.2 Voltage disturbance ride-through requirements
    - ⋮
    - 6.4.2.6 Dynamic voltage support

IEEE 1547 Technical Functions and Requirements

- S6: Response to Area EPS abnormal conditions
  - 6.5 Frequency [Reliability]
    - 6.5.1 Mandatory frequency tripping requirements
    - 6.5.2 Frequency disturbance ride-through requirements
    - ⋮
    - 6.5.2.5 Rate of change of frequency (ROCOF) ride-through
    - 6.5.2.6 Voltage phase angle changes ride-through
    - 6.5.2.7 Frequency-droop (frequency-power)
  - 6.6 Return to service after trip [Reliability]
- S8: Islanding [Reliability]
  - 8.1 Unintentional islanding
  - 8.2 Intentional islanding

IEEE 1547 Technical Functions and Requirements

- S4.7: Prioritization of DER responses [Manufacturer]
- S4.11 – 4.13: General
  - 4.11 Interconnect integrity [Reliability]
  - 4.12 Integration with Area EPS grounding [Reliability]
  - 4.13 Exemptions for Emergency Systems and Standby DER [Reliability, Interconnection]
- S7: PQ [Reliability, Interconnection]
- 11.4 Fault current characterization

- S9: Secondary network [no networks in Carolinas]

IEEE 1547 Information and Interoperability Requirements

- S10.1 – 10.4: Information Exchange and Models [Reliability (as required for a reliably function), Interconnection]
  - 10.1 Interoperability requirements
  - 10.2 Monitoring, control, and information exchange requirements
  - 10.3 – 10.6 DER Information
  - 10.7 Communication protocol requirements
  - 10.8 Communication performance requirements
  - 10.9 Cyber security requirements
- S11: Test and verification [Interconnection]
  - Design, Installation, Commissioning, Commissioning, Periodic tests and verifications

Poll Instructions

- After the meeting, complete the poll to prioritize the list
- Submit to Duke

1547 Section	Topic	Duke Order	Section Poll
4.2	Reference points of applicability (RPA) [Interconnection]	3	
4.3	Applicable voltages [Manufacturer]	3	
4.5	Cease to energize performance requirement [Reliability]	3	
4.6.1	Capability to disable permit service	21	
4.6.2	Capability to limit active power	21	
4.6.3	Execution of mode or parameter changes [Manufacturer]	9	
4.7	Prioritization of DER responses	22	
4.8	Isolation device [Interconnection]	23	
4.9	Inadvertent energization of the Area EPS [Interconnection]	8	
4.10	Enter service [Reliability] // 6.6 Return to service after trip	2	
4.10.2	Enter service criteria	2	
4.10.3	Performance during entering service	2	

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Stakeholder Feedback Form

Topic	Stakeholder	Comments	Proposals

Discussion

- Are the proper IEEE 1547-2018 functions or requirements?
- Is the proposed order the proper order?
- By what process should the remaining items be prioritized or ordered, the poll?
- What should the development and implementation schedule look like?
- Is the TSRG the proper stakeholder membership

- Is it right that Interoperability and Communication be established early on to facilitate the other functions, data, and monitoring?
- Is it right that Test and Verification requirements be developed incrementally as the function and requirements are implemented?

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Duke Energy Inverter Volt-VAR Functionality Study
January 21, 2020

Duke Energy inverter Volt-Var Functionality Study

Stakeholder Meeting

Date:01/21/2020

DUKE ENERGY®

Agenda

- Ground Rules
- Guiding Principles
- Logistics
- Timeline
- Overview of Volt-Var Functionality Study
- Preliminary Results of Volt-Var Study
  - DEC system
  - DEP system
  - Summary of Results
- Next Steps

Ground Rules

- All Stakeholder Group meetings, webinars and information exchange are designed solely to provide an open forum or means for the expression of various points of view in compliance with antitrust laws.
- Under no circumstances shall Stakeholder Group activities be used as a means for competing companies to reach any understanding, expressed or implied, which tends to restrict competition, or in any way, to impair the ability of participating members to exercise independent business judgment regarding matters affecting competition or regulatory positions.
- Proprietary information shall not be disclosed by any participant during any group meetings. In addition, no information of a secret or proprietary nature shall be made available to Stakeholder Group members.
- All proprietary information which may nonetheless be publicly disclosed by any participant during any group meeting shall be deemed to have been disclosed on a non-confidential basis, without any restrictions on use by anyone, except that no valid copyright or patent right shall be deemed to have been waived by such disclosure.

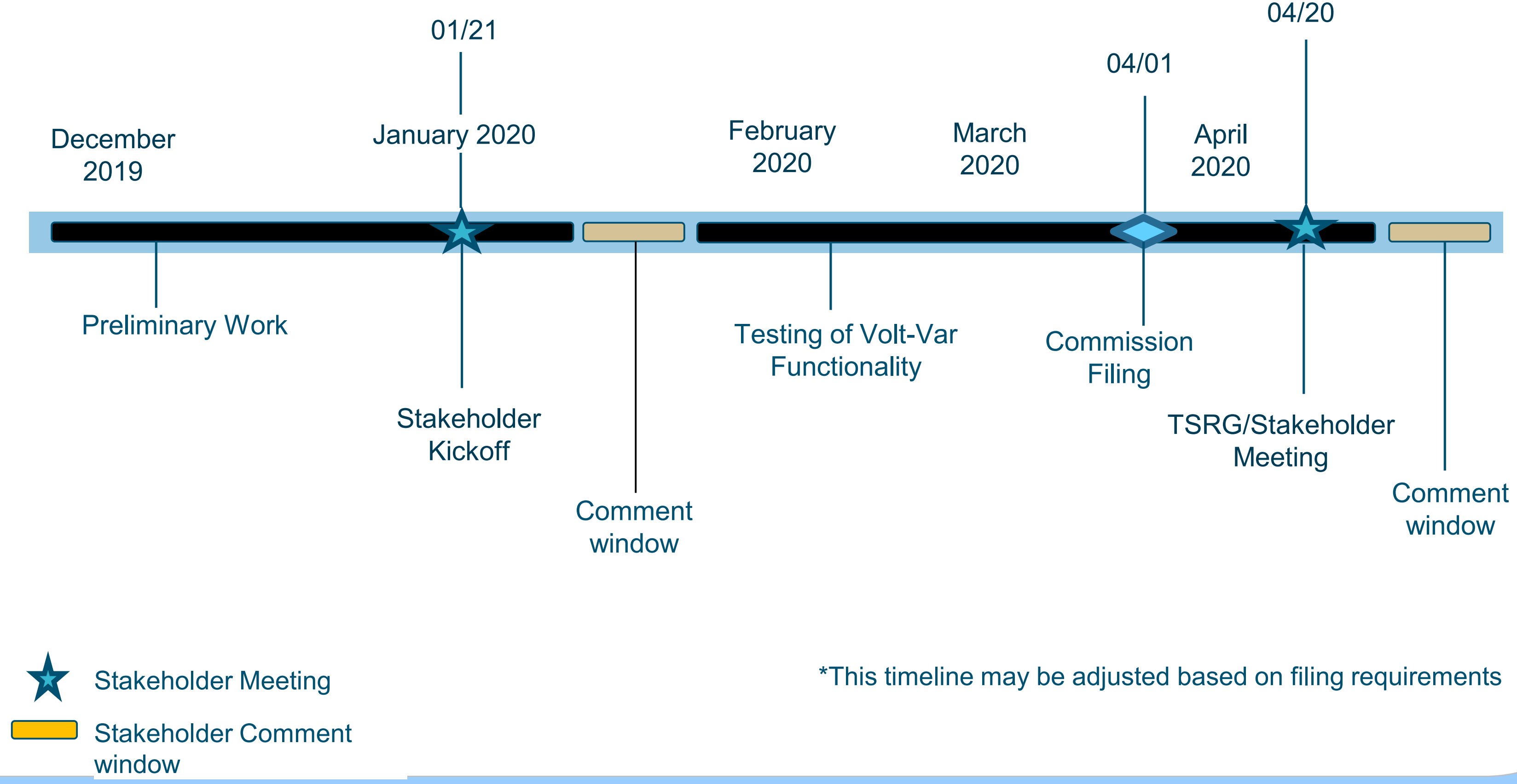
Guiding Principles

- North Carolina Commission had tasked Duke to evaluate software-based controls of advanced inverters according to IEEE 1547-2018 standard.
- Evaluate the use of autonomous voltage-reactive power control functions at multiple inverter-based distributed energy resources connected to the same feeder. Understand whether and how these controls cooperate with existing integrated voltage and VAR control systems.
- Evaluate the benefit of distributed voltage-reactive power controls at the distribution feeder level.
- Evaluate mitigation options required at the distribution feeder level to enable inverter reactive power based voltage control
- Conduct stakeholder process for inverter Volt-Var control functionalities consistent with IEEE 1547-2018 and the NC commission order.

Logistics

- Today's presentation will be distributed
- Clarifying questions will be answered during the presentation and stakeholder discussions at the end of the presentation
- Written feedback and comments will be solicited using comment form
- Comment form will be distributed along with presentation after the meeting
- Share the feedback form using email: Duke-IEEE1547@duke-energy.com for stakeholders to provide their written feedback

Volt-Var Functionality Study Project Timeline*



*This timeline may be adjusted based on filing requirements

Overview of Volt-Var Functionality Study

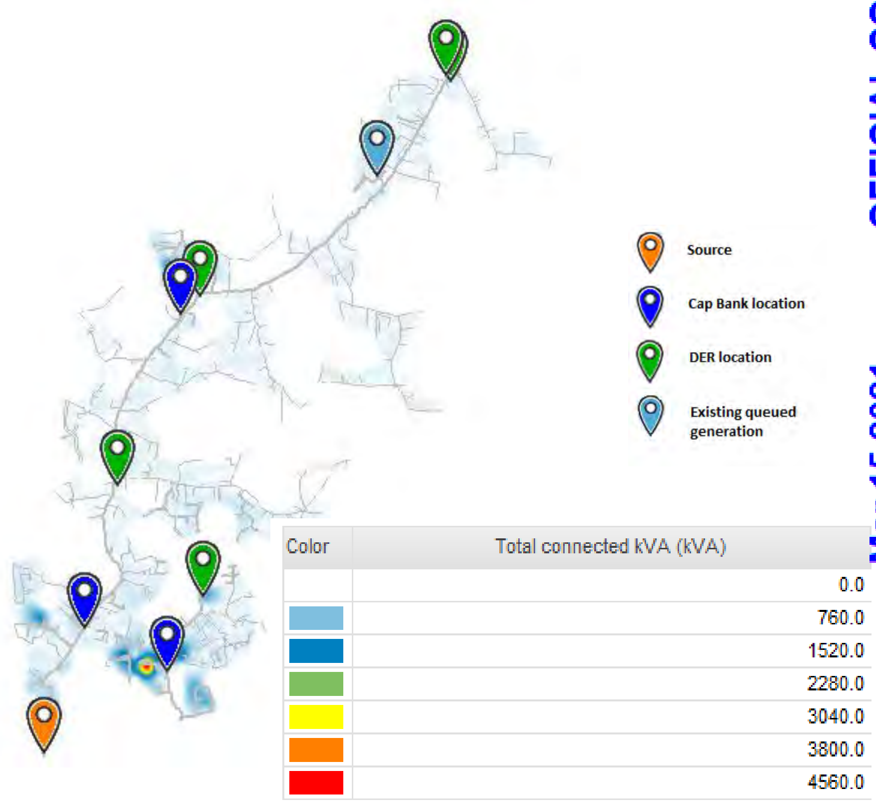
Tasks	1. Prepare Study	2. Conduct the Study and Stakeholder feedback	3. Final Deliverables
Key Steps	• Identify feeders, banks, and substations for testing • Collect input data and begin the model development process • Determine the number of controller configurations per feeder model • Power system model alignment that includes CYME	• Develop Scenarios • For the control settings determine approximate Var compensation magnitude and suggested source/equipment on high-level • Evaluate performance of Control functions using long rem dynamic analysis module • Obtain Stakeholder feedback	Developing a report that includes • DER volt-var optimization Results • Findings and recommendations

Inverter Volt-Var Functionality - Study (DEC System)

- Feeder description – Feeder A off-peak

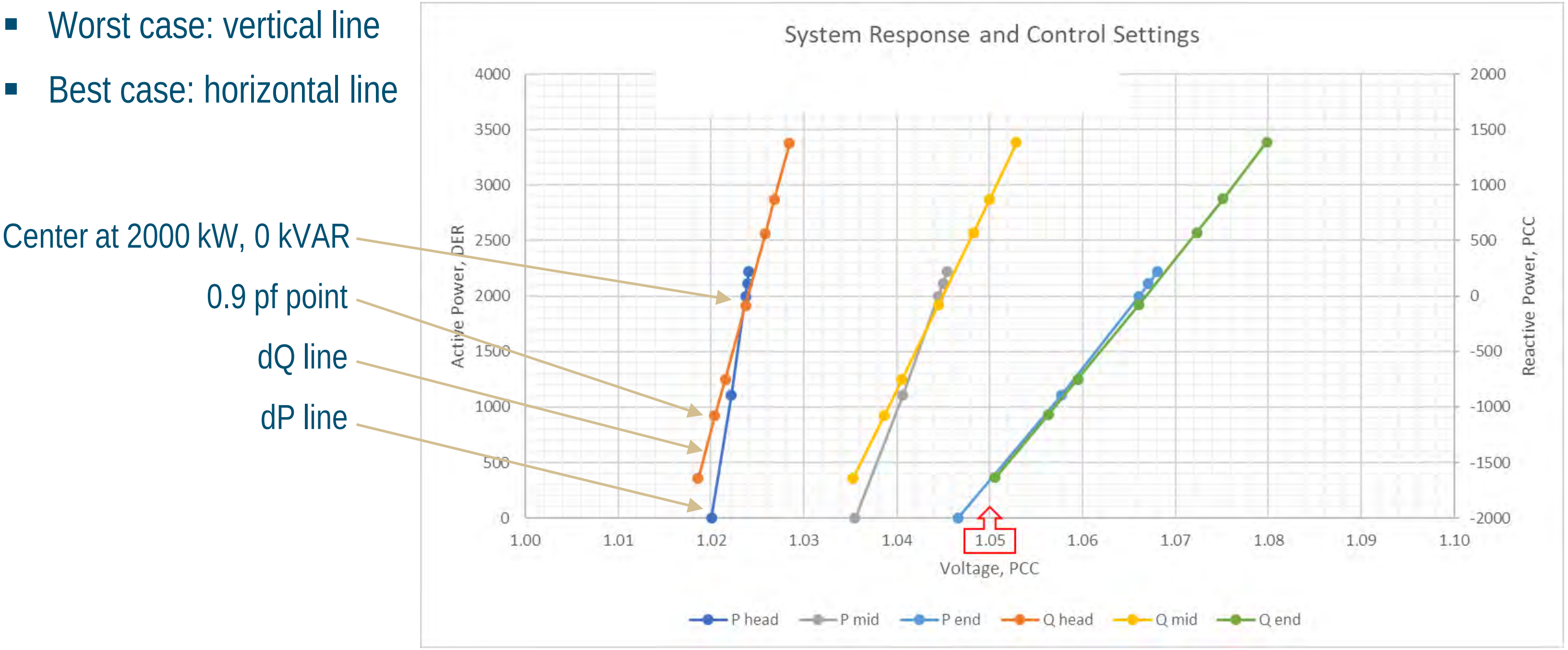
Feeder load characteristics	Value
Total load KW	1606.9
Total load Kvar	425.6
load PF	96.7%
Total load KVA	1662.3
Total KVA (peak load)	13735.6
Total load as a % of peak load	12.1%

Generation*	Value
Existing queued generation (end of feeder)	336 KW
Generation with smart inverter capability modeled at the head section	4 MW
Generation with smart inverter capability modeled at the middle section	2 MW
Generation with smart inverter capability modeled at the end section	4 MW



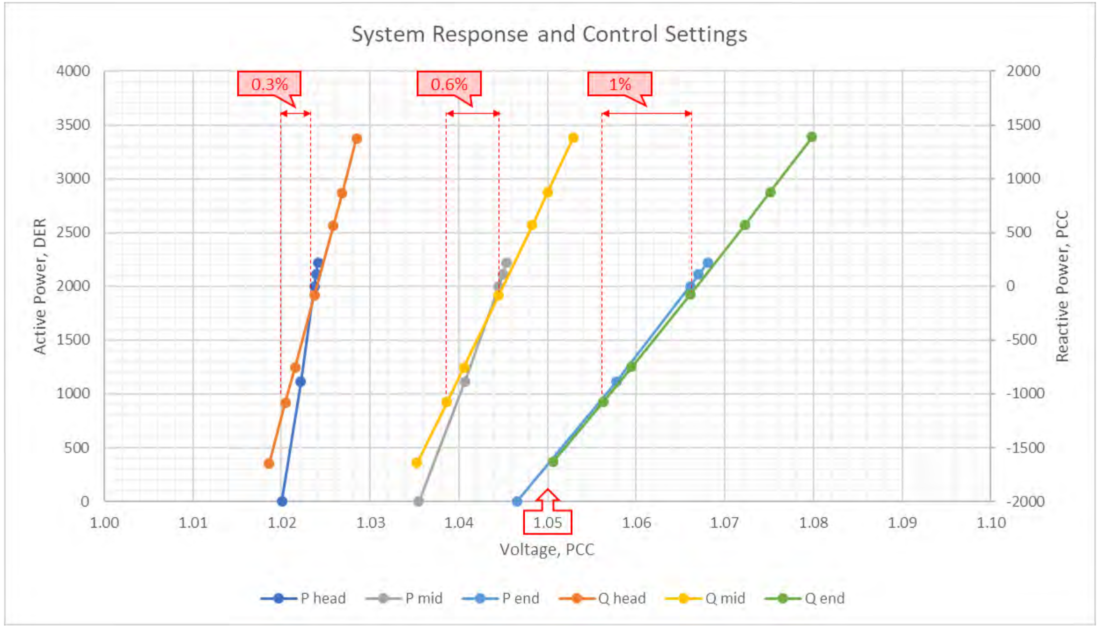
DER Ability to Control Voltage

- Displays impact of injecting active and reactive power: dV/dP, dV/dQ
- Indicates there is limited ability to impact voltage and the ability changes based on location
- Worst case: vertical line
- Best case: horizontal line



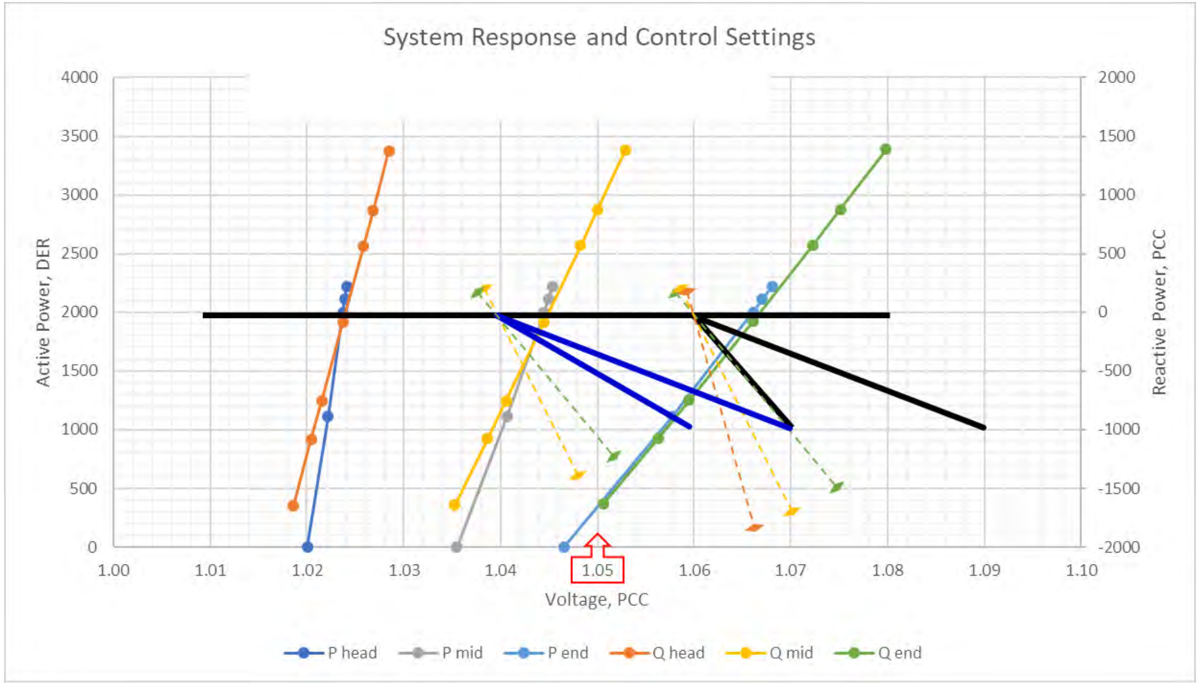
Initial Conclusions from Charts

- Reactive power voltage control is limited to 0.3 - 1.0 %; even at 0.9 pf operation
- Only one location exceeds 1.05 V pu at unity
  - So, at that location, volt-var has impact
  - At the other locations, watt-var more likely to work or even a non-unity pf
  - And volt-watt at end would be an option
- The system response varies between 0.3 – 1.0 % dV pu/dQmax
  - Not a large control range or impact
  - Input to consider for controller slope limit



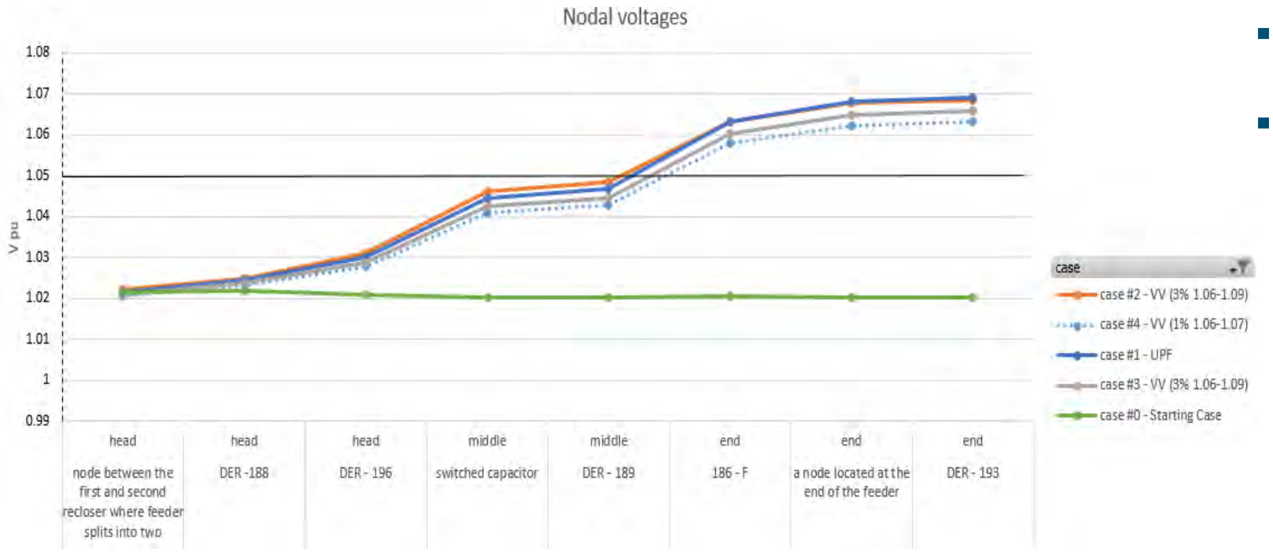
Application to Settings

- Can add the controller lines directly on the chart
  - Deadband in the center, blue lines for 1.04 initiation, black lines for 1.06 initiation
- Controller slope options considered are shown
- Dashed lines represent the system response slopes; by color
- The goal is to keep the controller slope to the right of the system response



Inverter Volt-Var functionality – Study (DEC System Off Peak)

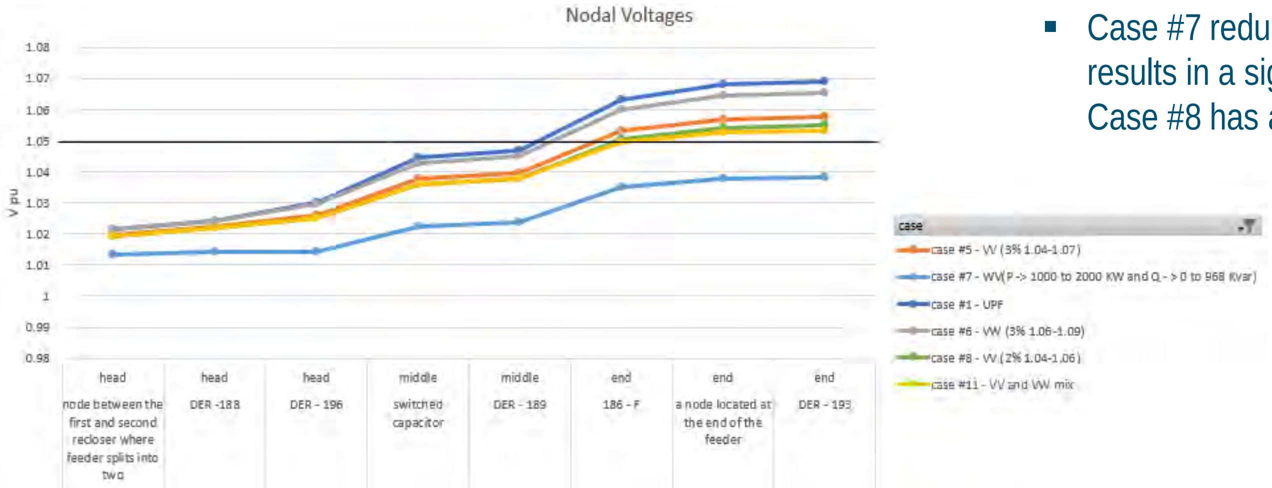
Cases	Caps	Number of DER units	Location	Control type	Control description	Gen outside 0.95 pf limit	Inverter KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #1	900 Kvar (head)	5	head,middle,end	Unity Power Factor	100%	No	2000	-170,-82,-158	-410
case #2	900 Kvar (head), 900 Kvar(middle)	3	head,middle	Volt-Var	3% from 1.06 to 1.09	No	2000	-170,-82	
case #2	900 Kvar (head), 900 Kvar(middle)	2	end	Volt-Var	3% from 1.06 to 1.09	No	2000	-730	-982
case #3	900 Kvar (head)	3	head, middle	Volt-Var	3% from 1.06 to 1.09	No	2000	-170,-82	
case #3	900 Kvar (head)	2	end	Volt-Var	3% from 1.06 to 1.09	No	2000	-507	-759
case #4	900 Kvar (head)	3	head, middle	Volt-Var	1% from 1.06 to 1.07	No	2000	-170,-82	
case #4	900 Kvar (head)	2	end	Volt-Var	1% from 1.06 to 1.07	No	2000	-784	-1036



- Case #4 was studied after reviewing results of Case #3.
- Case #4 has a better voltage response but still doesn't mitigate overvoltage.

Inverter Volt-Var functionality – Study (DEC System Off Peak)

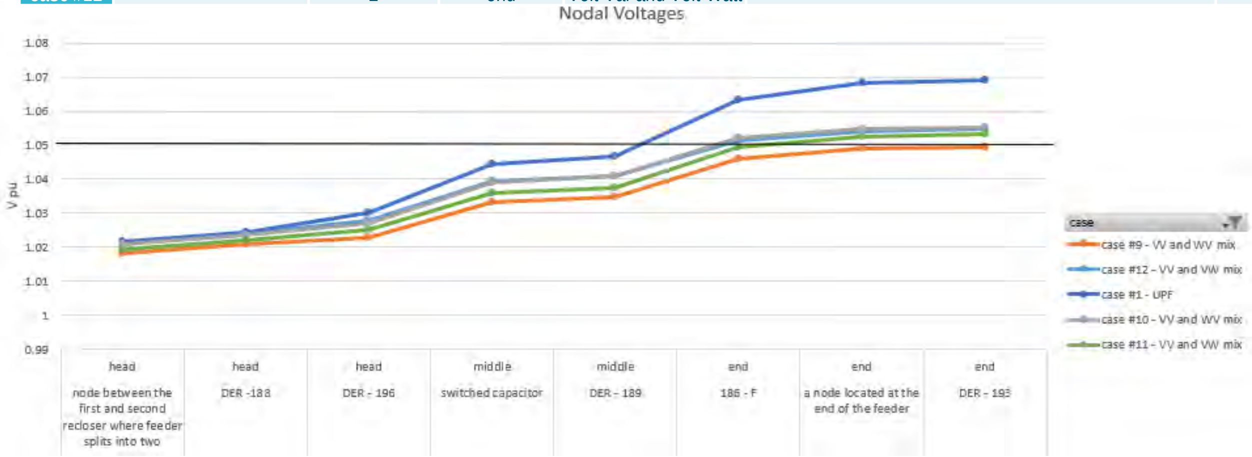
Cases	Caps	Number of DER units	Location	Control type	Control description	Gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #5	900 Kvar (head)	2	head	Volt-Var	3% from 1.04 to 1.07	No	2000	-170	
case #5	900 Kvar (head)	1	middle	Volt-Var	3% from 1.04 to 1.07	No	2000	-190	-1696
case #5	900 Kvar (head)	2	end	Volt-Var	3% from 1.04 to 1.07	No	2000	-1336	
case #6	900 Kvar (head)	3	head,middle	Volt-Watt	3% from 1.06 to 1.09	No	2000	-170,-82	-379
case #6	900 Kvar (head)	2	end	Volt-Watt	3% from 1.06 to 1.09	No	1793	-127	
case #7	900 Kvar (head)	5	head,middle,end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2162,-1079,-2150	-5391
case #8	900 Kvar (head)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-170	
case #8		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-148	-1938
case #8	900 Kvar (head)	2	end	Volt-Var	2% from 1.04 to 1.06	Yes	2000	-1620	



- Case #7 reduces voltage below 1.05 pu, but results in a significant reactive power absorption. Case #8 has a better voltage response.

Inverter Volt-Var functionality – Study (DEC System Off Peak)

Cases	Caps	Number of DER units	location	Control type	Control description	Gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #9	900 Kvar (head)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-172	-2412
case #9		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-97	
case #9		2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2143	
case #10	2400 Kvar (head), 900 Kvar (middle)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-170	-2432
case #10		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-115	
case #10		2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2147	
case #11	900 Kvar (head)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-170	-1671
case #11		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-122	
case #11		2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	No	1816	-1379	
case #12	1700 Kvar (head), 900 Kvar (middle)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-186	-1929
case #12		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-195	
case #12		2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	Yes	1702	-1548	



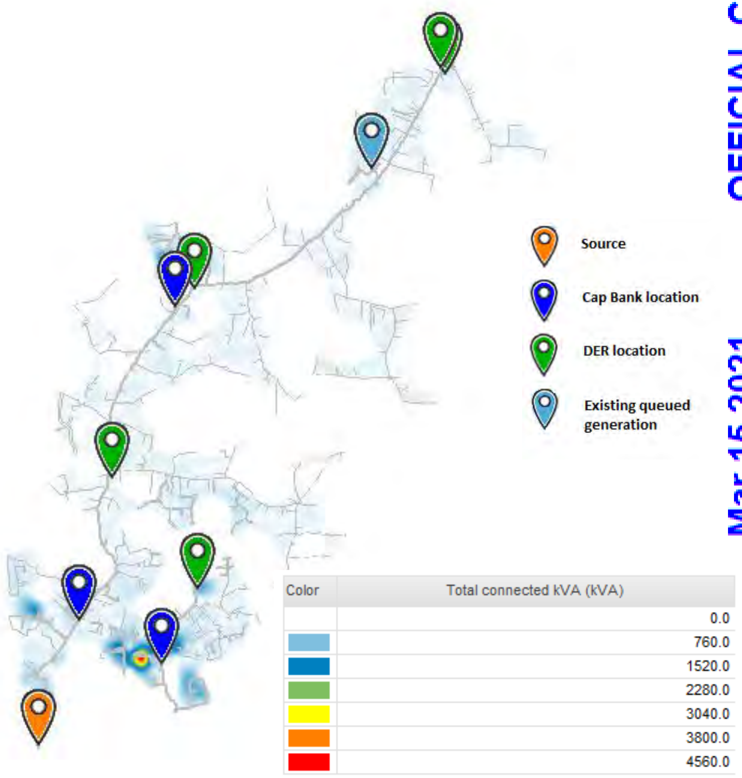
- Case #9 provides the most optimal response and reduce voltage below 1.05 pu.
- However, Case #9 has an 800 KVAR higher reactive requirement than Case #11.

Inverter Volt-Var functionality – Study (DEC System Shoulder Peak)

- Feeder description – Feeder A shoulder peak

Feeder load characteristics	Value
Total load KW	8879.7
Total load Kvar	2105.4
load PF	97.3%
Total load KVA	9125.9
Total KVA (peak load)	13735.6
Total load as a % of peak load	66.4%

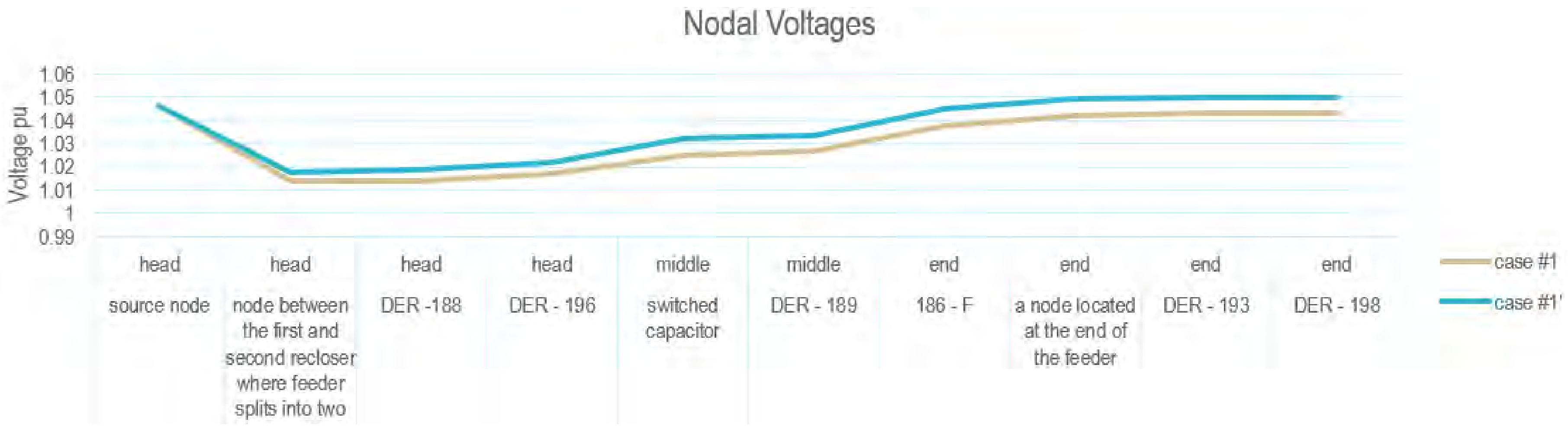
Generation*	Value
Existing queued generation (end of feeder)	336 KW
Generation with smart inverter capability modeled at the head section	4 MW
Generation with smart inverter capability modeled at the middle section	2 MW
Generation with smart inverter capability modeled at the end section	4 MW



Inverter Volt-Var Functionality – Study (DEC System Shoulder Peak)

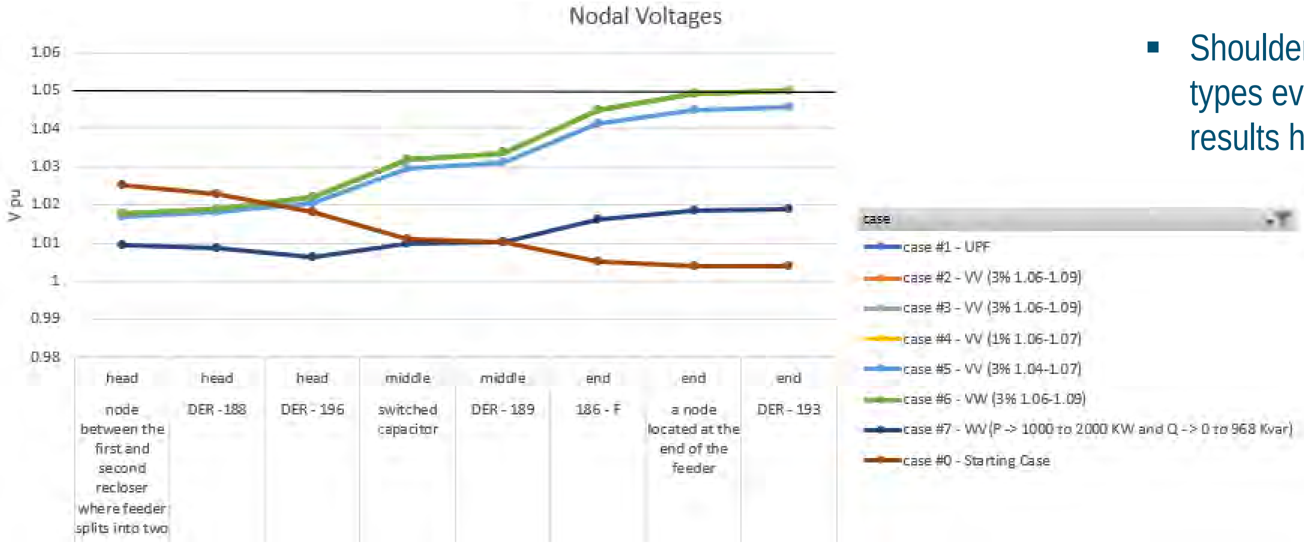
- Case Description – shoulder peak

Case	Caps	Regulator	Location	Control Type	Control Outline
case #1	offline	-5,-6,-4	head,middle and end	unity power factor	Unity power factor
case #1'	900 Kvar (head), 600 Kvar (head), 900 Kvar (middle)	-5,-6,-4	head,middle and end	unity power factor	Unity power factor



Inverter Volt-Var functionality – Study (DEC System Shoulder Peak)

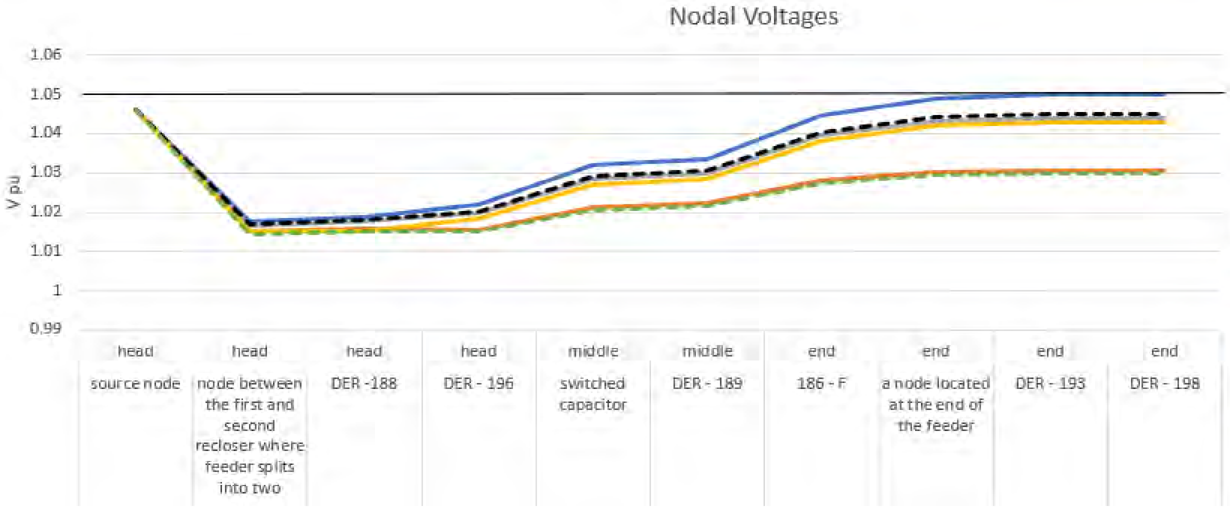
Case	Caps	Number of DER units	Location	Control type	Control description	gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #1	1500 Kvar (head), 900 Kvar (middle)	5	head,middle,end	Unity Power Factor	100%	No	2000	-170,-82,-158	-410
case #2, #3, #4	1500 Kvar (head), 900 Kvar (middle)	3	head,middle,end	Volt-Var	3% from 1.06 to 1.09	No	2000	-170,-82,-158	-410
case #5	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	3% from 1.04 to 1.07	No	2000	-170,-84	-826
case #5	1500 Kvar (head), 900 Kvar (middle)	2	end	Volt-Var	3% from 1.04 to 1.07	No	2000	-572	
case #6	1500 Kvar (head), 900 Kvar (middle)	5	head,middle,end	Volt-Watt	3% from 1.06 to 1.09	No	2000	-170,-82,-158	-410
case #7	1500 Kvar (head), 900 Kvar (middle)	5	head,middle,end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	--2162,-1079,-2158	-5399



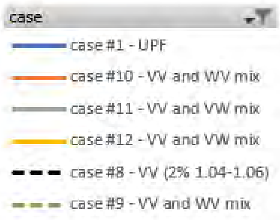
- Shoulder peak cases were tested for control types evaluated for the off-peak case to see if results hold true in the shoulder peak case

Inverter Volt-Var functionality – Study (DEC System Shoulder Peak)

Case	Caps	Number of DER units	location	Control type	Control description	Gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #8	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-170,-148	-978
case #8	1500 Kvar (head), 900 Kvar (middle)	2	end	Volt-Var	2% from 1.04 to 1.06	No	2000	-660	
case #9	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-172,-86	-2412
case #9	1500 Kvar (head), 900 Kvar (middle)	2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2154	
case #10	3900 Kvar (head), 900 (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-172,-86	-2412
case #10	3900 Kvar (head), 900 (middle)	2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2154	
case #11	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-170,-148	-978
case #11	1500 Kvar (head), 900 Kvar (middle)	2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	No	2000	-660	
case #12	2500 Kvar (head), 900 (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-170,148	-1030
case #12	2500 Kvar (head), 900 (middle)	2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	No	2000	-712	



- The results indicate, control setpoint picked for off-peak would work for shoulder-peak as well.
- The reactive compensation is also set by the off-peak case

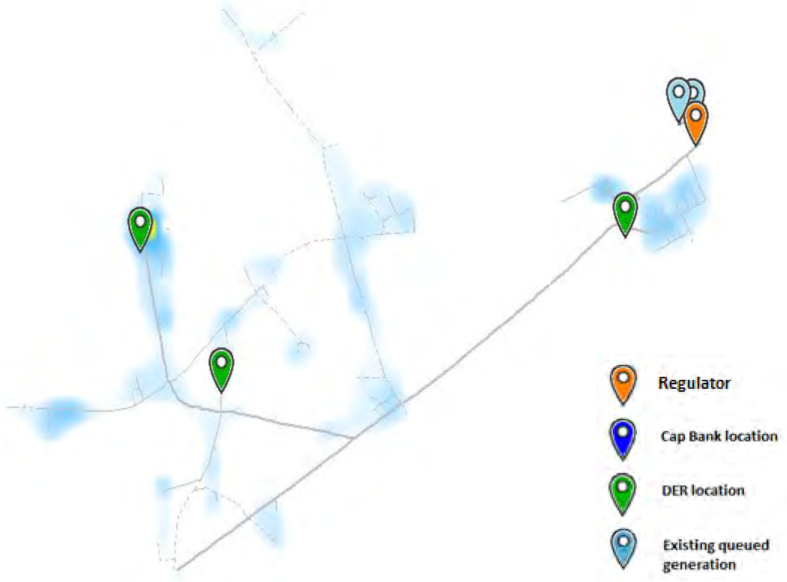


Inverter Volt-Var functionality - Study (DEP System Off-Peak)

- Feeder B description – off-peak

Feeder load characteristics	Value
Total load KW	252.2
Total load Kvar	94.7
load PF	94.0%
Total load KVA	269.4
Total KVA (peak load)	7103.8
Total load as a % of peak load	3.8%

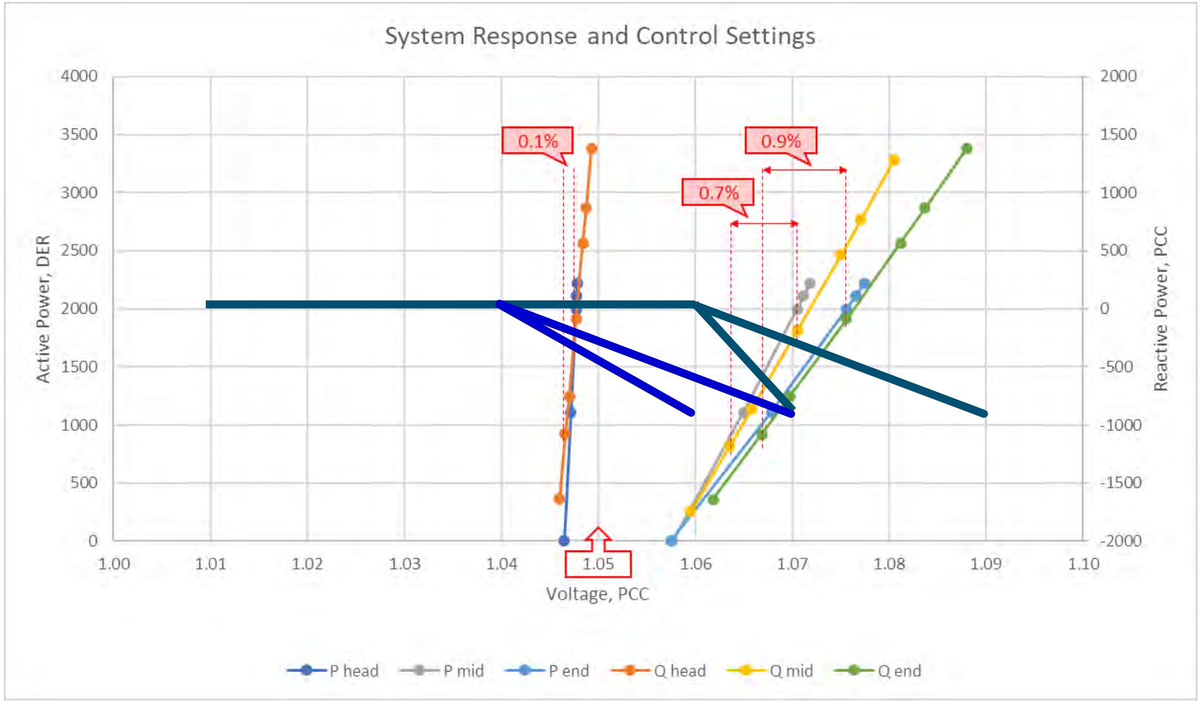
Generation*	Value
Existing queued generation (head of the feeder)	10 MW
Generation with smart inverter capability modeled at the head section	2 MW
Generation with smart inverter capability modeled at the middle section	2 MW
Generation with smart inverter capability modeled at the end section	2 MW



Color	Total connected kVA (kVA)
	0.0
(light blue)	178.3
(yellow)	356.7
(red)	535.0

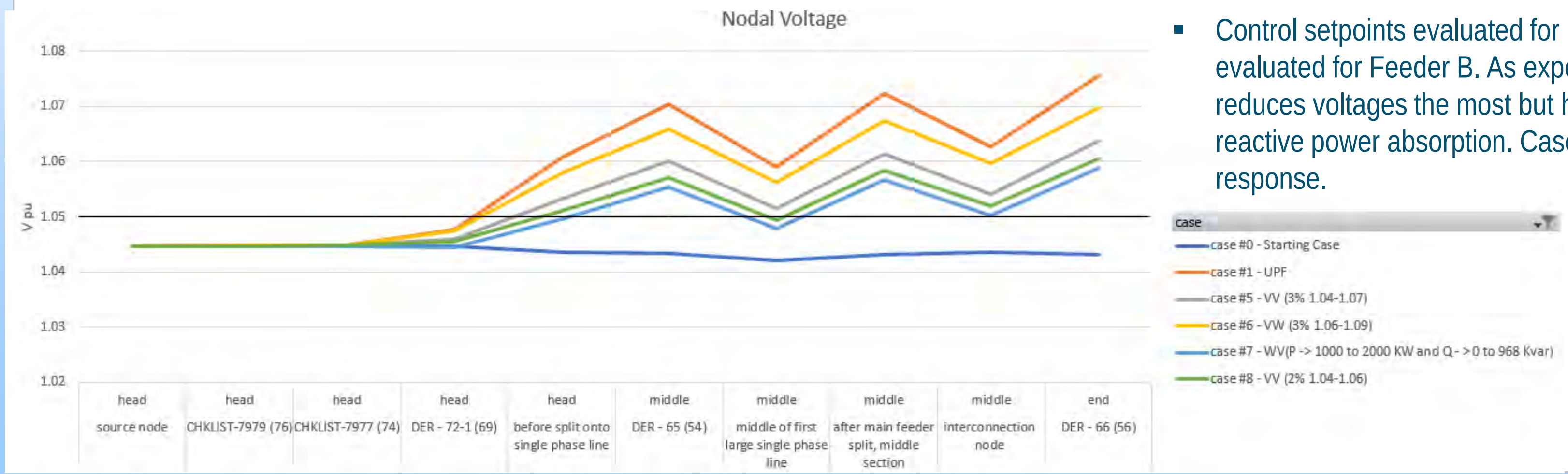
Application to Settings

- The response at the end of the feeder is similar to the previous circuit
- The response at the head is much lower
- The last two controllers are electrically close, that indicates similar controls should be effective
- Given the voltage at the head, the first DER is likely to operate absorbing
- The last two DER are expected to operate near reactive limit



Inverter Volt-Var functionality – Study (DEP System Off-Peak)

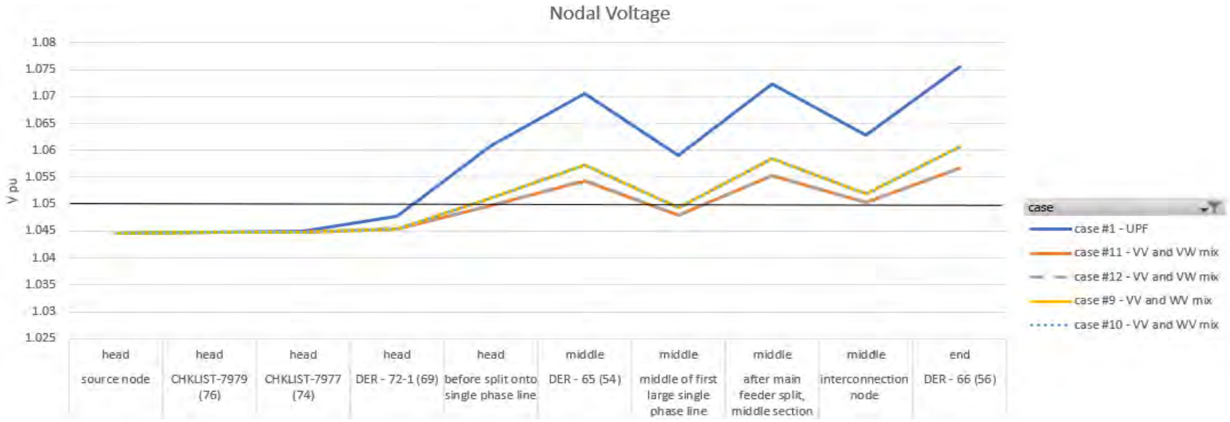
Case	Caps	Number of DER units	Location	Control type	control outline	gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	total Kvar
case #1	none	3	head,middle,end	Unity Power Factor	Unity Power Factor	No	2000	-82,-78,-86	-246
case #5	none	1	head	volt-var	3% from 1.04 to 1.07	No	2000	-276	
case #5	none	1	middle	volt-var	3% from 1.04 to 1.07	No	1999	-744	-1897
case #5	none	1	end	volt-var	3% from 1.04 to 1.07	Yes	1999	-877	
case #6	none	1	head	volt-watt	3% from 1.06 to 1.09	No	2000	-82	
case #6	none	1	middle	volt-watt	3% from 1.06 to 1.09	No	1769	-63	-198
case #6	none	1	end	volt-watt	3% from 1.06 to 1.09	No	1490	-53	
case #7	none	3	head,middle,end	watt-var	P_1000->2000kW Q_0-928kVAR or 0.9 pf	Yes	2000	-1075,-1072,-1078	-3225
case #8	none	1	head	volt-var	2% from 1.04 to 1.06	No	2000	-347	
case #8	none	1	middle	volt-var	2% from 1.04 to 1.06	Yes	1999	-923	-2341
case #8	none	1	end	volt-var	2% from 1.04 to 1.06	Yes	1999	-1071	



- Control setpoints evaluated for Feeder A were also evaluated for Feeder B. As expected, Case #7 reduces voltages the most but has a very high reactive power absorption. Case #8 has a better response.

Inverter Volt-Var functionality – Study (DEP System Off-Peak)

Case	Caps	Number of DER units	Location	control type	control outline	gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	total Kvar
case #9	none	1	head	volt-var	2% from 1.04 to 1.06	No	2000	-346	-2341
case #9	none	1	middle	volt-var	2% from 1.04 to 1.06	Yes	1999	-923	
case #9	none	1	end	watt-var	P_1000->2000kW Q_0-928kVAR or 0.9 pf	Yes	1999	-1072	
case #10	2400 Kvar (head)	1	head	volt-var	2% from 1.04 to 1.06	No	2000	-346	-2341
case #10	2400 Kvar (head)	1	middle	volt-var	2% from 1.04 to 1.06	Yes	1999	-923	
case #10	2400 Kvar (head)	1	end	watt-var	P_1000->2000kW Q_0-928kVAR or 0.9 pf	Yes	1999	-1072	
case #11	none	1	head	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	No	2000	-352	-1934
case #11	none	1	middle	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1679	-752	
case #11	none	1	end	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1449	-830	
case #12	2000 Kvar (head)	1	head	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	No	2000	-352	-1934
case #12	2000 Kvar (head)	1	middle	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1679	-752	
case #12	2000 Kvar (head)	1	end	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1449	-830	



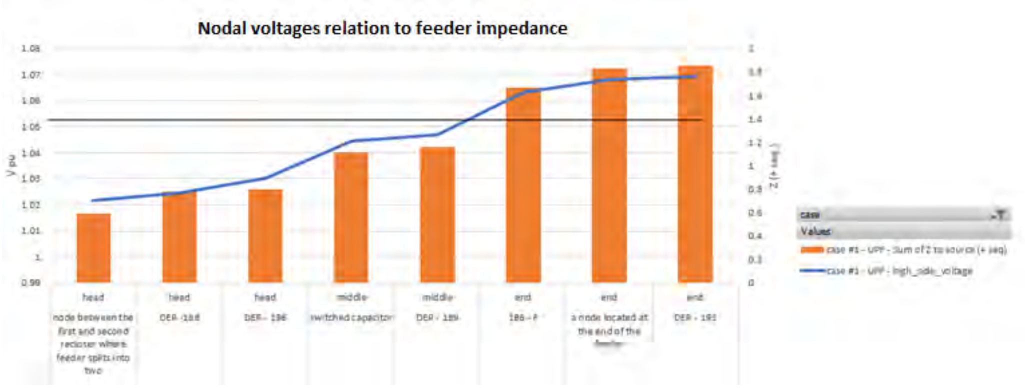
- Case #9 and Case #11 have better voltage responses. Case #11 reduces active power, whereas Case#9 results in an additional 400 KVAR reactive power absorption as compared to Case #11.

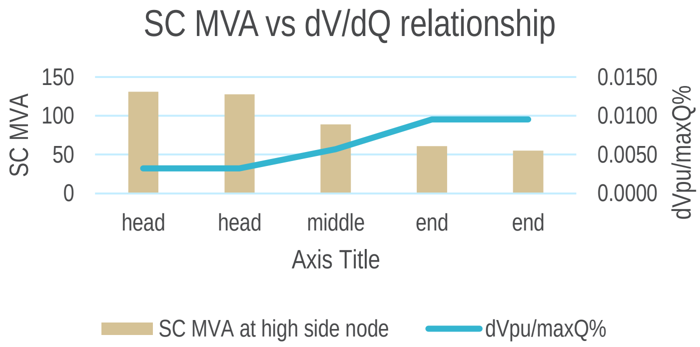
Inverter Volt-Var functionality

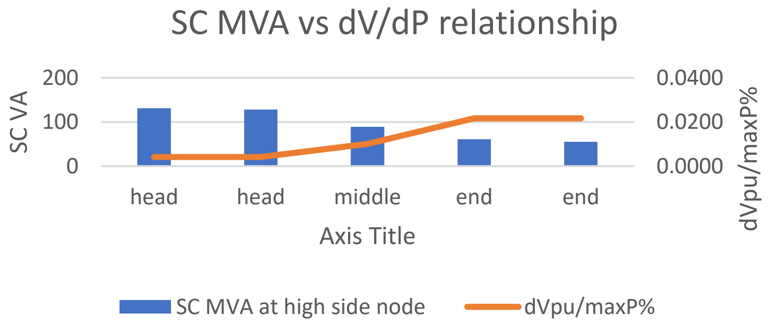
- Summary of Results:
  - The control settings evaluated for Feeder A were also evaluated for Feeder B.
  - Study indicates a standalone volt-var controller is not sufficient to mitigate voltage issues for DER units at the end of the feeder. dP/dV and dQ/dV curves confirm this result as well.
  - dP/dV and dQ/dV curves also indicate limited voltage control would be available for units at the head of the feeder.
  - Volt-Var control in combination with Volt-Watt control or a standalone Watt-Var controller could work for units at the end of the feeder.
  - Universal controller could work:
    - Best controller for Feeder A off-peak would also work for Feeder A shoulder-peak and other loading conditions.
    - The same controller for Feeder A could work for Feeder B. Studies on additional feeders would give an indication on this.

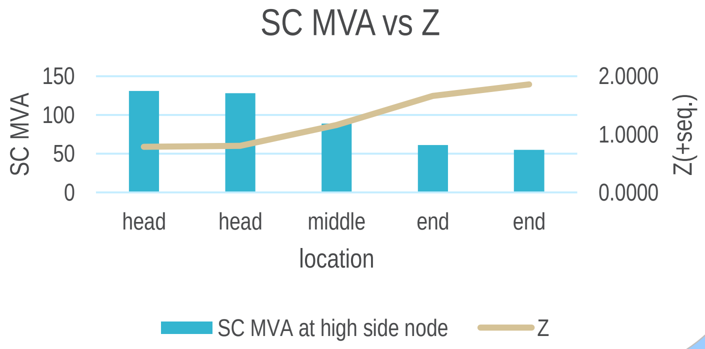
Inverter Volt-Var Functionality

- Come up with control strategies based on generation and feeder characteristics, for example feeder impedance values, X/R ratio, short circuit MVA at PCC.









Inverter Volt-Var functionality – Next Steps

- Incorporate stakeholder feedback into these first 2 feeders
- Set up the testing parameters for the remaining 4 feeders.
- Apply dV/dP and dV/dQ calculations in determining appropriate control methodology and control settings.
- For the optimized control settings determine approximate Var compensation magnitude and suggested source/equipment on high-level (if any needed) to maintain the power factor (or reactive power) at the feeder and bank level.
  - Provide reactive compensation equal to the reactive power absorbed at the DER PCC
- Evaluate if a universal controller is effective for all the circuits.
- Set the long-term dynamic profiles with the identified load and irradiance profiles and simulate test days with the optimized control settings.

Stakeholder Feedback Form

Topic	Stakeholder	Comments	Proposals

DUKE ENERGY®

Update and Discussion: Action Plan to Implement 1547-2018
April 28, 2020

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting

Anthony C Williams, P.E.
Principal Engineer

DER Technical Standards
April 28, 2020

DUKE ENERGY®

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Agenda

- Setting priorities
- Selected order
- Next steps
- Discussion

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Ground Rules

- All Stakeholder Group meetings, webinars and information exchange are designed solely to provide an open forum or means for the expression of various points of view in compliance with antitrust laws.
- Under no circumstances shall Stakeholder Group activities be used as a means for competing companies to reach any understanding, expressed or implied, which tends to restrict competition, or in any way, to impair the ability of participating members to exercise independent business judgment regarding matters affecting competition or regulatory positions.
- Proprietary information shall not be disclosed by any participant during any group meetings. In addition, no information of a secret or proprietary nature shall be made available to Stakeholder Group members.
- All proprietary information which may nonetheless be publicly disclosed by any participant during any group meeting shall be deemed to have been disclosed on a non-confidential basis, without any restrictions on use by anyone, except that no valid copyright or patent right shall be deemed to have been waived by such disclosure.

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Logistics

- Clarifying questions will be answered during the presentation and stakeholder discussions at the end of the presentation
- Written feedback and comments will be solicited using comment form
  - Note questions then lets discuss – don't really want all the questions sent in that are mainly just for clarification – this takes a lot of time to address that could be spent on the comments and recommendations
  - It would be helpful to provide more Comment and Proposed Change details :

Stakeholder Name	Page Number	Paragraph Number	Comment	Proposed Change
example Question format	3	2	Why is winter data excluded?	None
example Comment format	7	4	Agree with the hours of study.	None
example Comment format	7	4	'the largest' is not clear	Replace 'the largest' with 'the maximum of the three phase currents"
example Recommendation format	10	3	The types of faults is too limited. Include single line to ground faults.	Include SLG faults

  - Being more specific makes the point, or main concerns, of the comment more apparent and allows a more direct response.
- Comments will be taken during the discussion and the form will be distributed after the meeting
- Share the feedback form using email: Duke-IEEE1547@duke-energy.com for stakeholders to provide their written feedback

General Guidance for Priorities

- Consider IEEE 1547 functions that could potentially increase the amount of DER capacity that could increase interconnection capability
  - 4.6.2 Capability to limit active power
  - 5.3 Voltage and reactive power control
  - 5.4 Voltage and active power control
- Consider IEEE 1547 sections that impact grid support
  - Mainly based on guidance from documents such as the NERC Reliability Guideline: Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018
- Stakeholder comments
- Implementation plan reviews from other utilities
- All these factors impacted the priority order

DUKE ENERGY.

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority Setting: 1st and 2nd Priority Example

Selected Order:

1. Topical Priority
2. Member Count
3. Member Average
4. Duke & NERC Average

IEEE 1547 Section	IEEE 1547-2018 Topic	TSRG Selected Order	Duke Order	NERC Relib Guide	Member 1	Member 2	Member 3	Member Count	Member Average	Count	Total	Average
5.2	**Reactive power capability of the DER**	1	1		1	3	3.1	3	2.4	4	8.1	2.0
5.3	**Voltage and reactive power control**	1	1		1	3	3.1	3	2.4	4	8.1	2.0
5.4.2	**Voltage-active power control**	1	1		1	3	3.1	3	2.4	4	8.1	2.0
7.4	Limitation of overvoltage contribution	1	7		1	2	4.1	3	2.4	4	14.1	3.5
7.2.3	Power Quality, Flicker	1	7		1	2	4.1	3	2.4	4	14.1	3.5
7.2.2	Power Quality, Rapid voltage change (RVC)	1	7		1	2	1	3	1.3	4	11.0	2.8
6.4.1	Mandatory voltage tripping requirements (OV/UV)	2	4	1	1	4	1	3	2.0	5	11.0	2.2
6.5.1	Mandatory frequency tripping requirements (OF/UF)	2	4	1	5	4	3	3	4.0	5	17.0	3.4
6.4.2	Voltage disturbance ride-through requirements	2	4	1	1	4	2	3	2.3	5	12.0	2.4
6.5.2	Frequency disturbance ride-through requirements	2	4	1	1	4	4	3	3.0	5	14.0	2.8
6.5.2.7	Frequency-droop (frequency-power) capability	2	7	1	1	4	5.1	3	3.4	5	18.1	3.6
6.5.2.6	Voltage phase angle changes ride-through	2	6	1	1	4	5.1	3	3.4	5	17.1	3.4

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority List Excerpt

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
1 (DUK-01)	5.2	Reactive power capability of the DER	Category B 35° C ambient or higher at rated voltage	No Reqmt	Eval + Comm Test
1 (DUK-02)	5.3	Voltage and reactive power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-03)	5.4.2	Voltage-active power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-04)	7.4	Limitation of overvoltage contribution	Pending. Likely requires more industry experience or analysis to address this issue	TBD	Eval + Comm Test
1 (DUK-05)	7.2.3	Power Quality, Flicker	Continue existing criteria and policy	No Reqmt	Eval + Comm Test
1 (DUK-06)	7.2.2	Power Quality, Rapid voltage change (RVC)	Continue existing criteria and policy	TBD	Eval + Comm Test

- Three summary columns on the right
- Provide general overview
- Refer to specific sections of the report for the details on that part of the Standard

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority Groups 1 – 5 Overview

1st	• Reactive power and voltage control • Power quality
2nd	• Voltage tripping and ride through • Frequency tripping and ride through
3rd	• Most important sections of Section 4, General Tech Specs
4th	• Most commonly applied sections of Section 4, General Tech Specs
5th	• Remaining sections of Section 4, General Tech Specs

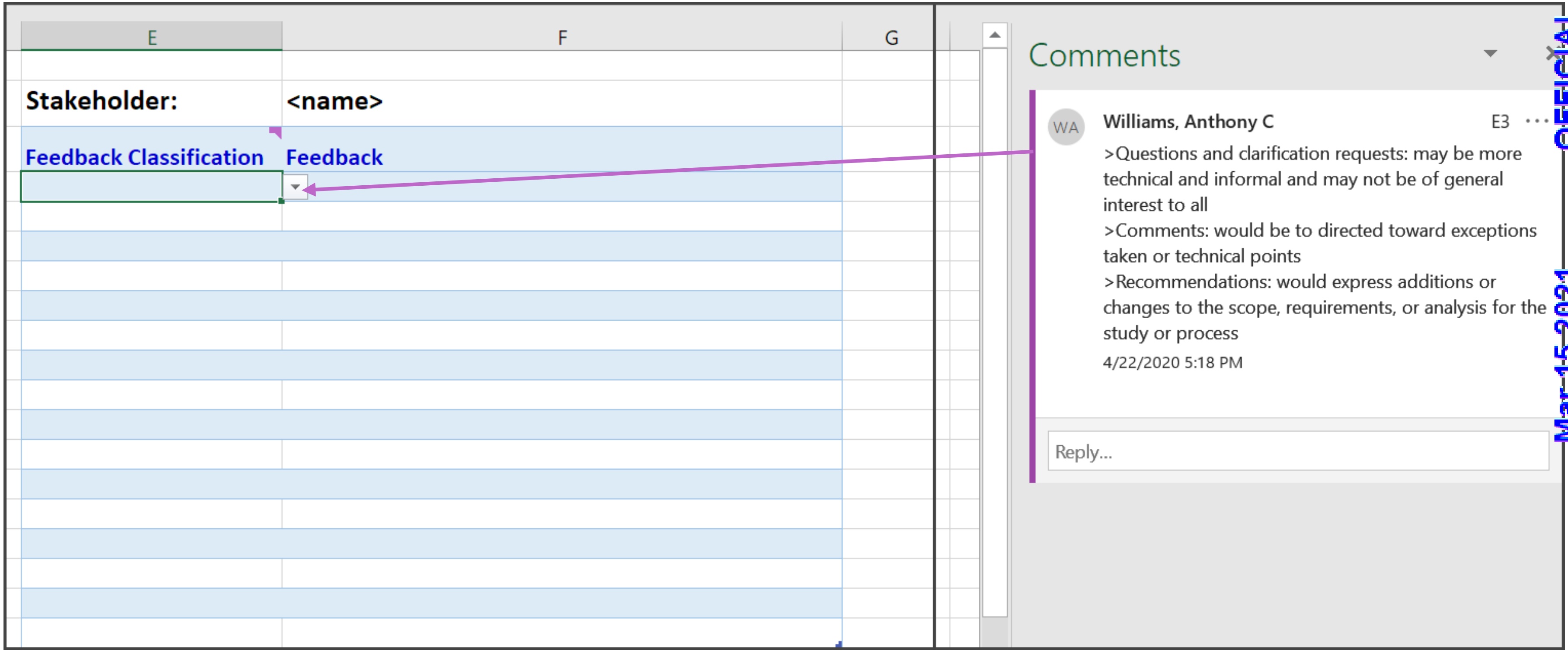
Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Recommended Next Steps

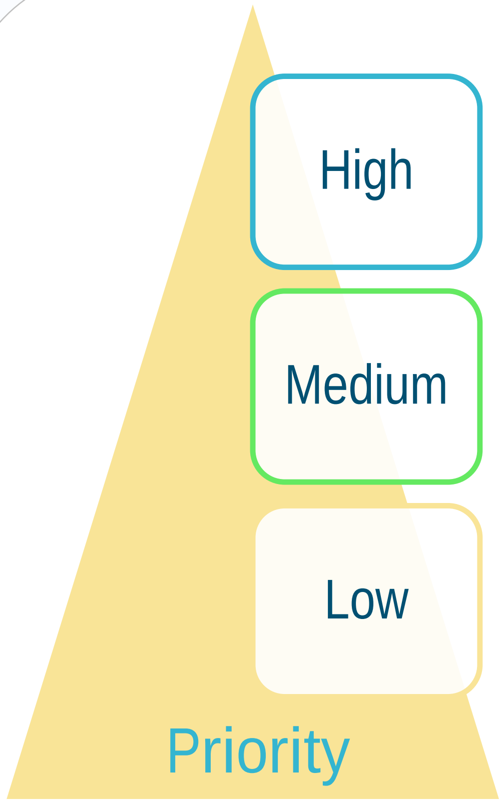
- Confirmation of the priority order
- Continue pursuing
  - Section 5 topics concerning – reactive power and voltage control
  - Section 6 O/UV and O/UF trip settings and ride through requirements
  - 3rd priority: most important general interconnection specifications and requirements
- More discussion or investigation of
  - 7.4 Limitation of overvoltage contribution
    - Seems to need more industry experience and analysis
    - Recommend moving this topic to 5th priority group
- Stage in 4th and 5th priority items after completing 3rd priority

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

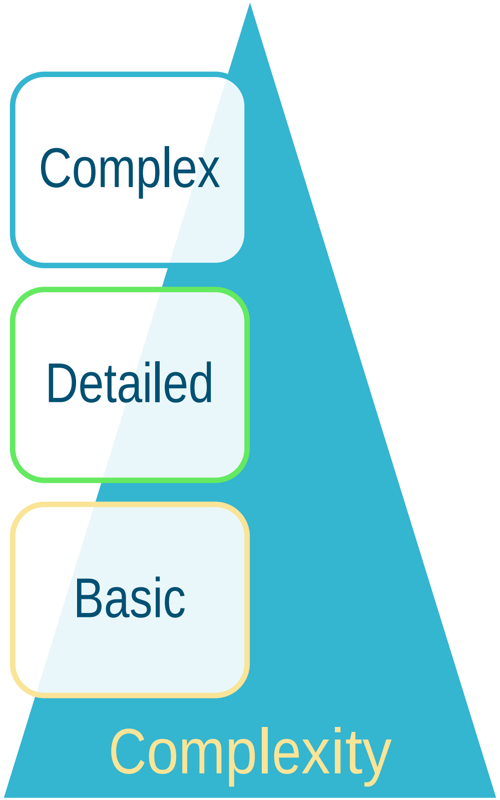
Stakeholder Feedback Form



Priority and Complexity



1. Functions that enable higher penetrations of DER
2. Rank topics based on stakeholder preference
3. Note that there will be a need to spread the more complex functions over time



Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Interconnection Related Functions

- Past TSRG input -- Functions that enable higher penetrations of DER
- The following functions in 1547 improve the capability of DER to interconnect:
  - 5.2 Reactive power capability of the DER
  - 5.3 Voltage and reactive power control
    - 5.3.2 Constant power factor mode
    - 5.3.3 Voltage-reactive power mode
    - 5.3.4 Active power-reactive power mode
    - 5.3.5 Constant reactive power mode
  - 5.4 Voltage and active power control
    - 5.4.2 Voltage-active power mode
  - 4.6.2 Capability to limit active power

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Interconnection Function Status

- Active evaluations
  - Starting with 5.3 Voltage and reactive power control
    - By necessity then, 5.2 Reactive power capability of the DER
  - Secondary focus on 5.4 Voltage and active power control
- Future evaluation
  - 4.6.2 Capability to limit active power
    - In a way, done now by restricting kW at SIS
    - Performing this during real time operations is complex
      - Implementation would need considerable investigation
- Three of these four more important functions are in progress

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Discussion

- Are the proper IEEE 1547-2018 functions or requirements?
- Is the proposed order the proper order?
- By what process should the remaining items be prioritized or ordered, the poll?
- What should the development and implementation schedule look like?
- Is the TSRG the proper stakeholder membership

- Is it right that Interoperability and Communication be established early on to facilitate the other functions, data, and monitoring?
- Is it right that Test and Verification requirements be developed incrementally as the function and requirements are implemented?

Update and Discussion: Inverter Volt-Var Impact Study TSRG Meeting
April 28, 2020

Update and Discussion: Inverter Volt-Var Impact Study
TSRG Meeting

Anthony C Williams, P.E.
Principal Engineer

DER Technical Standards

April 28, 2020

DUKE ENERGY®

Agenda

- Review the study
- Review the results
- Review the recommendations
- Next Steps and stakeholder discussion

Ground Rules

- All Stakeholder Group meetings, webinars and information exchange are designed solely to provide an open forum or means for the expression of various points of view in compliance with antitrust laws.
- Under no circumstances shall Stakeholder Group activities be used as a means for competing companies to reach any understanding, expressed or implied, which tends to restrict competition, or in any way, to impair the ability of participating members to exercise independent business judgment regarding matters affecting competition or regulatory positions.
- Proprietary information shall not be disclosed by any participant during any group meetings. In addition, no information of a secret or proprietary nature shall be made available to Stakeholder Group members.
- All proprietary information which may nonetheless be publicly disclosed by any participant during any group meeting shall be deemed to have been disclosed on a non-confidential basis, without any restrictions on use by anyone, except that no valid copyright or patent right shall be deemed to have been waived by such disclosure.

Logistics

- Clarifying questions will be answered during the presentation and stakeholder discussions at the end of the presentation
- Written feedback and comments will be solicited using comment form
  - Note questions then lets discuss – don't really want all the questions sent in that are mainly just for clarification – this takes a lot of time to address that could be spent on the comments and recommendations
  - It would be helpful to provide more Comment and Proposed Change details :

Stakeholder Name	Page Number	Paragraph Number	Comment	Proposed Change
example Question format	3	2	Why is winter data excluded?	None
example Comment format	7	4	Agree with the hours of study.	None
example Comment format	7	4	'the largest' is not clear	Replace 'the largest' with 'the maximum of the three pha[se] currents"
example Recommendation format	10	3	The types of faults is too limited. Include single line to ground faults.	Include SLG faults

  - Being more specific makes the point, or main concerns, of the comment more apparent and allows a more direct response.
- Comments will be taken during the discussion and the form will be distributed after the meeting
- Share the feedback form using email: Duke-IEEE1547@duke-energy.com for stakeholders to provide their written feedback

Study Overview

- North Carolina Commission had tasked Duke to evaluate software-based controls of advanced inverters according to IEEE 1547-2018 standard.
- Evaluate the use of autonomous voltage-reactive power control functions at multiple inverter-based distributed energy resources connected to the same feeder. Understand whether and how these controls cooperate with existing integrated voltage and VAR control systems.
- Evaluate the benefit of distributed voltage-reactive power controls at the distribution feeder level.
- Evaluate mitigation options required at the distribution feeder level to enable inverter reactive power based voltage control
- Conduct stakeholder process for inverter Volt-Var control functionalities consistent with IEEE 1547-2018 and the NC commission order.
- Comments remain open on the April report until June 1, 2020

Study Conclusions

- Several forms of control, setpoints, and combinations were considered
  - Under the study conditions a Volt-Var controller with 2% voltage slope between 1.04-1.06 pu, in combination with a Volt-Watt controller with 3% voltage slope between 1.06-1.09 pu will appears capable of reducing overvoltage conditions.
- Category B provides the most flexibility and margin for system changes over time
- DER near the station reduces the voltage concerns, reduces the reactive power flow, reduces the effectiveness of the inverter control, and reduces reactive capability requirements
- Once the voltage increases from DER interconnection, it generally remains elevated instead of returning to a lower level as load increases

Study Recommended Next Steps

- Conduct time series power flow studies to look at system response over many hours
- Voltage controller concerns
  - With the IVVC commitments, how will those controls manage DER reactive power if something other than a fixed pf is used
  - Consider how to control the feeder head compensation capacitor with autonomous controls
  - Impact on feeders with regulators that use resistive drop compensation; could require significant feeder changes if the drop compensation is removed to accommodate DER reactive power control
  - Use the time series to investigate how well the existing voltage control device controllers manage the DER reactive power
- Consider controls that get more var absorption to hold voltage under 1.05
- Review the impact of higher var absorption on the feeders (closer examination of reactive power flow on the feeder)
- Consider pf based controls for voltage independence and voltage reference to absorb less reactive power at steady state
- Identify potential pilot sites; following further clarification from the additional steps above

Stakeholder Feedback Form

Stakeholder Name	Page Number	Paragraph Number	Comment	Proposed Change

Voltage Regulation Configurations

- Variety of the voltage regulation on the 6 feeders

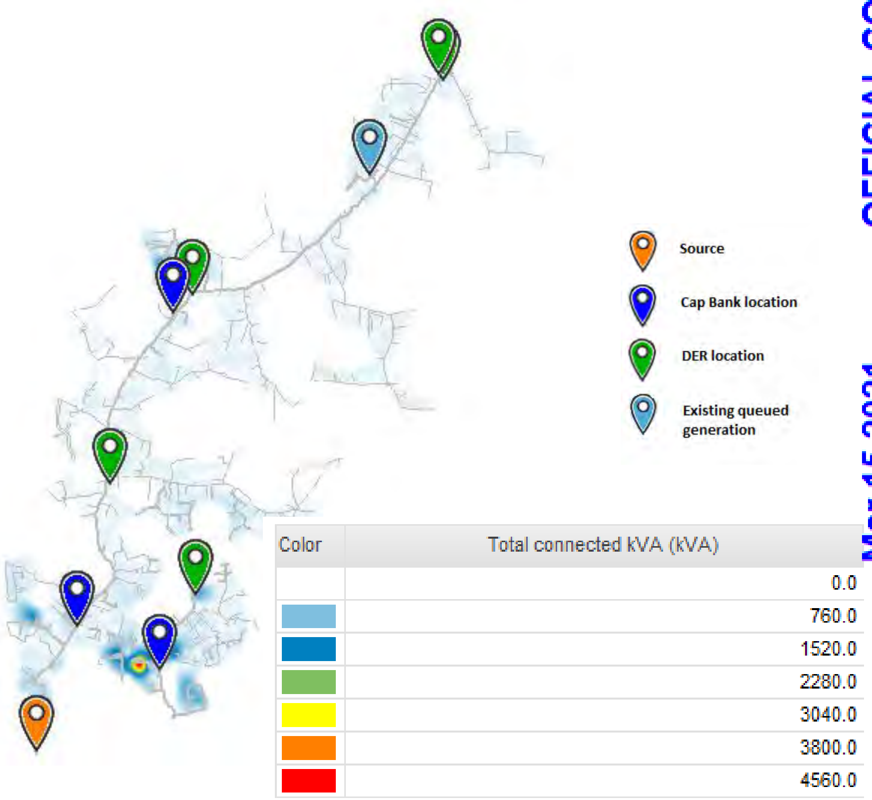
DEC	DEC	DEP	DEC	DEP	DEP	
Feeder B	Feeder C	Feeder D	Feeder A	Feeder F	Feeder E	
		X				Line Reg
			X			Feeder Reg
	X			X*		Feeder & Line Regs
					X*	LTC/Bus Reg
X						LTC/Bus Reg

Inverter Volt-Var Functionality - Study (DEC System)

- Feeder description – Feeder A off-peak

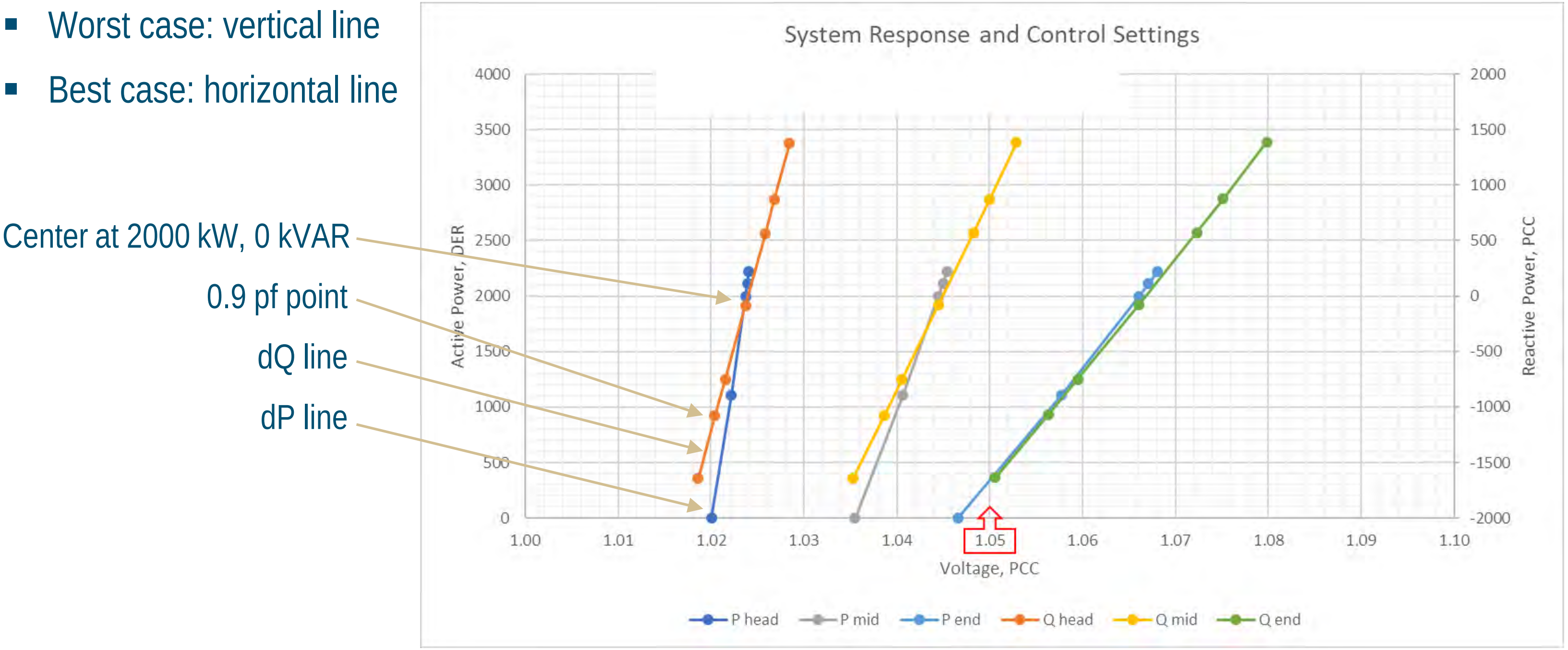
Feeder load characteristics	Value
Total load KW	1606.9
Total load Kvar	425.6
load PF	96.7%
Total load KVA	1662.3
Total KVA (peak load)	13735.6
Total load as a % of peak load	12.1%

Generation*	Value
Existing queued generation (end of feeder)	336 KW
Generation with smart inverter capability modeled at the head section	4 MW
Generation with smart inverter capability modeled at the middle section	2 MW
Generation with smart inverter capability modeled at the end section	4 MW



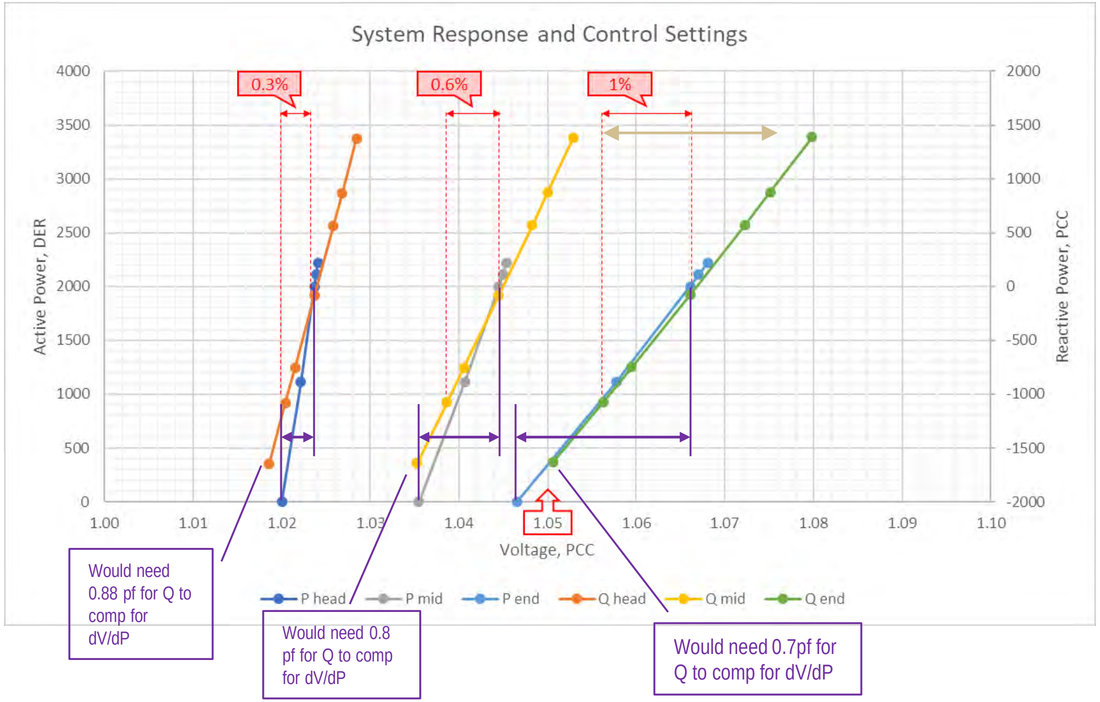
DER Ability to Control Voltage

- Displays impact of injecting active and reactive power: dV/dP, dV/dQ
- Indicates there is limited ability to impact voltage and the ability changes based on location
- Worst case: vertical line
- Best case: horizontal line



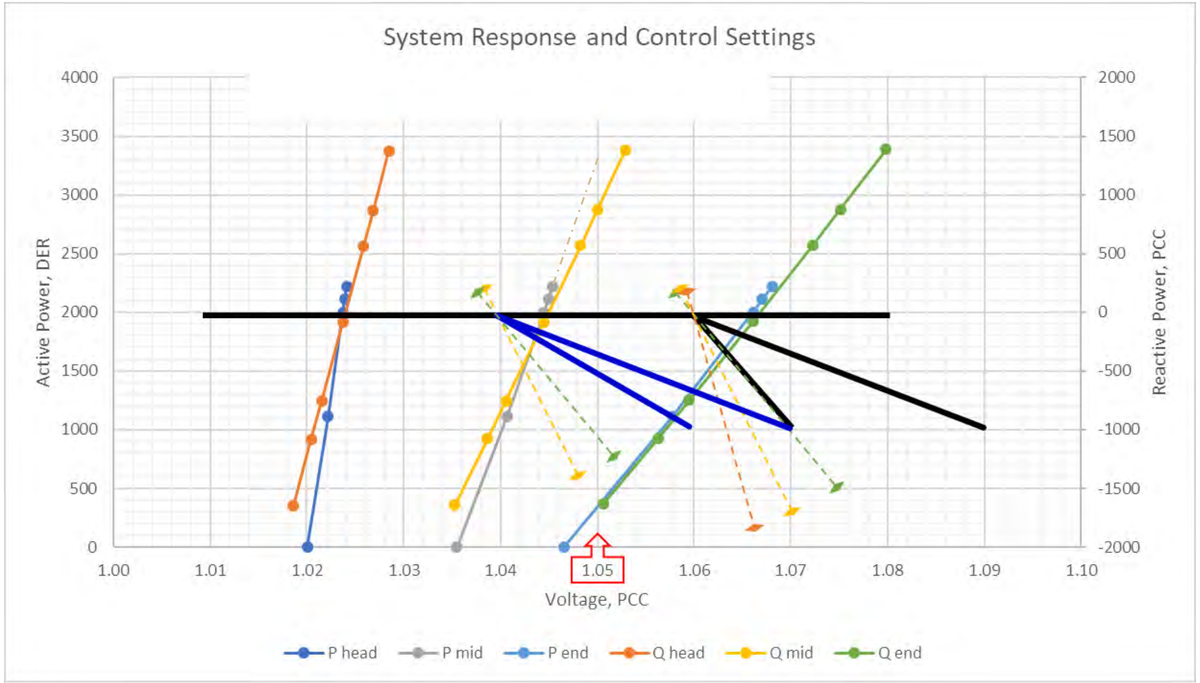
Initial Conclusions from Charts

- Reactive power voltage control is limited to 0.3 - 1.0 %; even at 0.9 pf operation
- Only one location exceeds 1.05 V pu at unity
  - So, at that location, volt-var has impact
  - At the other locations, watt-var more likely to work or even a non-unity pf
  - And volt-watt at end would be an option
- The system response varies between 0.3 – 1.0 % dV pu/dQmax
  - Not a large control range or impact
  - Input to consider for controller slope limit



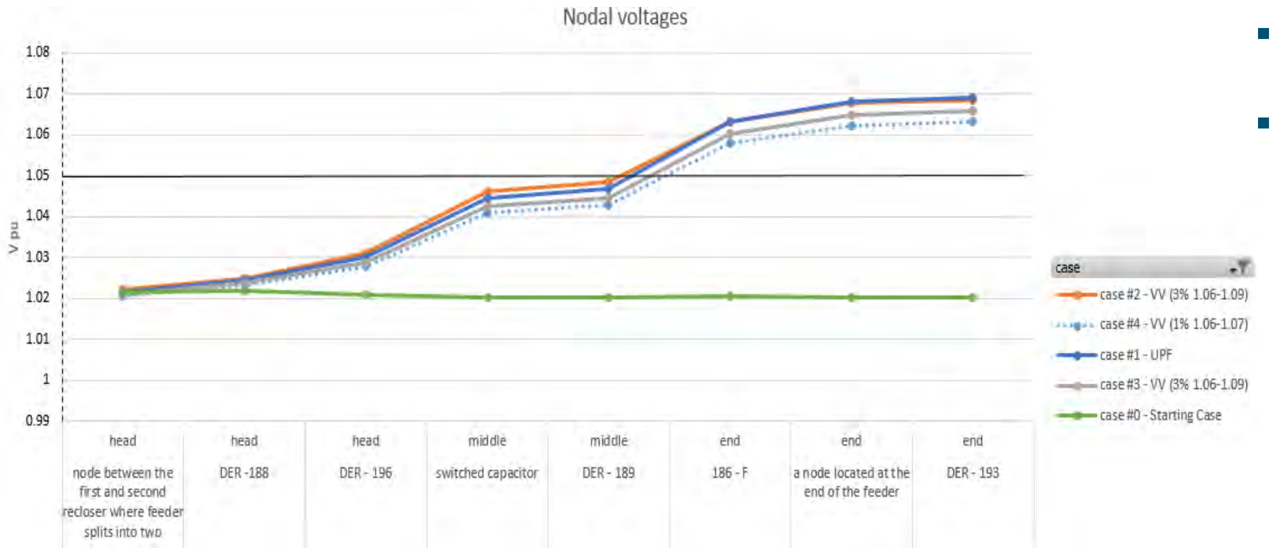
Application to Settings

- Can add the controller lines directly on the chart
  - Deadband in the center, blue lines for 1.04 initiation, black lines for 1.06 initiation
- Controller slope options considered are shown
- Dashed lines represent the system response slopes; by color
- The goal is to keep the controller slope to the right of the system response



Inverter Volt-Var functionality – Study (DEC System Off Peak)

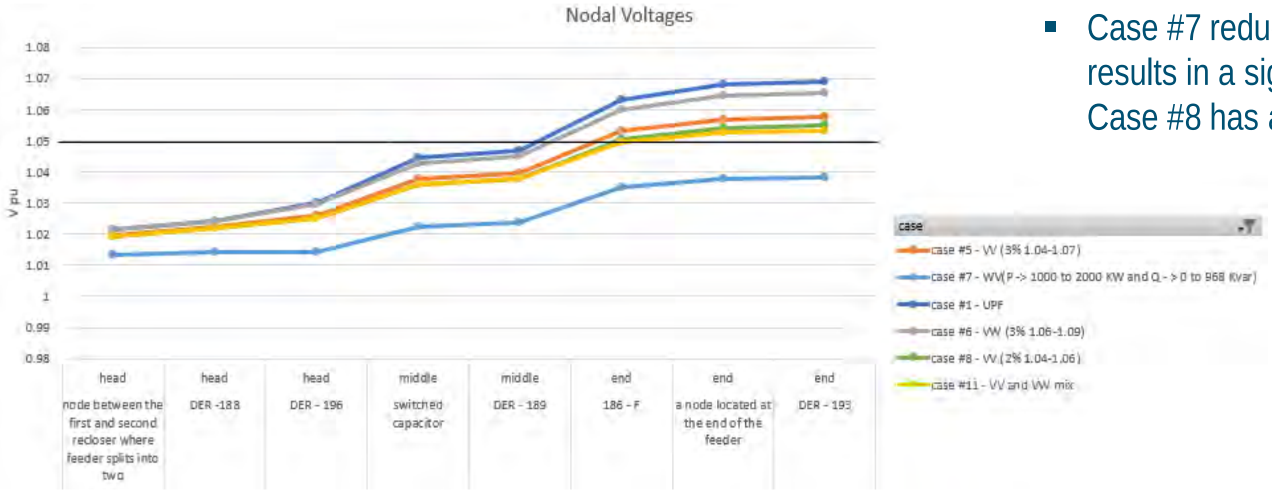
Cases	Caps	Number of DER units	Location	Control type	Control description	Gen outside 0.95 pf limit	Inverter KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #1	900 Kvar (head)	5	head,middle,end	Unity Power Factor	100%	No	2000	-170,-82,-158	-410
case #2	900 Kvar (head), 900 Kvar(middle)	3	head,middle	Volt-Var	3% from 1.06 to 1.09	No	2000	-170,-82	
case #2	900 Kvar (head), 900 Kvar(middle)	2	end	Volt-Var	3% from 1.06 to 1.09	No	2000	-730	-982
case #3	900 Kvar (head)	3	head, middle	Volt-Var	3% from 1.06 to 1.09	No	2000	-170,-82	
case #3	900 Kvar (head)	2	end	Volt-Var	3% from 1.06 to 1.09	No	2000	-507	-759
case #4	900 Kvar (head)	3	head, middle	Volt-Var	1% from 1.06 to 1.07	No	2000	-170,-82	
case #4	900 Kvar (head)	2	end	Volt-Var	1% from 1.06 to 1.07	No	2000	-784	-1036



- Case #4 was studied after reviewing results of Case #3.
- Case #4 has a better voltage response but still doesn't mitigate overvoltage.

Inverter Volt-Var functionality – Study (DEC System Off Peak)

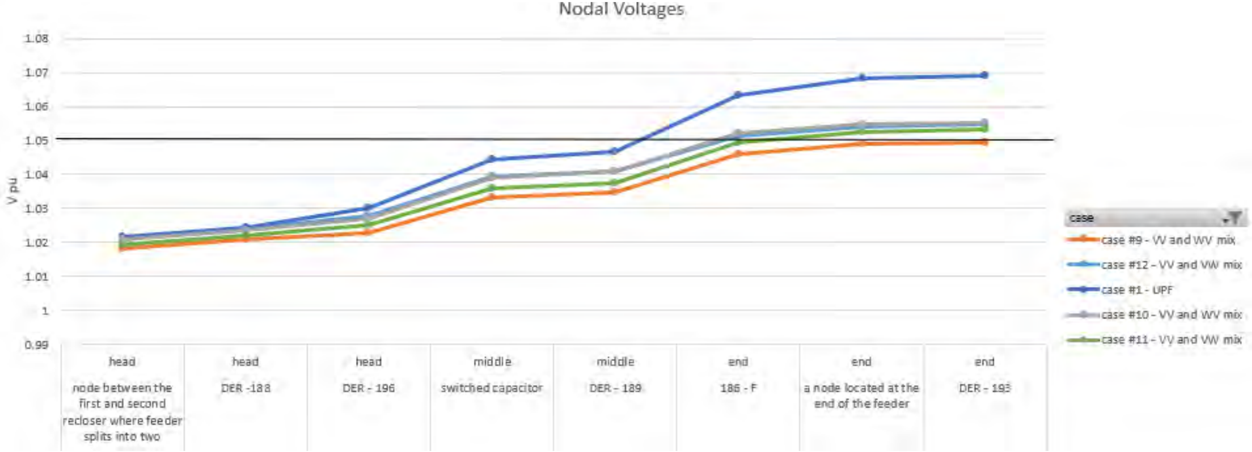
Cases	Caps	Number of DER units	Location	Control type	Control description	Gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #5	900 Kvar (head)	2	head	Volt-Var	3% from 1.04 to 1.07	No	2000	-170	-1696
case #5	900 Kvar (head)	1	middle	Volt-Var	3% from 1.04 to 1.07	No	2000	-190	
case #5	900 Kvar (head)	2	end	Volt-Var	3% from 1.04 to 1.07	No	2000	-1336	
case #6	900 Kvar (head)	3	head,middle	Volt-Watt	3% from 1.06 to 1.09	No	2000	-170,-82	-379
case #6	900 Kvar (head)	2	end	Volt-Watt	3% from 1.06 to 1.09	No	1793	-127	
case #7	900 Kvar (head)	5	head,middle,end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2162,-1079,-2150	-5391
case #8	900 Kvar (head)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-170	-1938
case #8		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-148	
case #8	900 Kvar (head)	2	end	Volt-Var	2% from 1.04 to 1.06	Yes	2000	-1620	



- Case #7 reduces voltage below 1.05 pu, but results in a significant reactive power absorption. Case #8 has a better voltage response.

Inverter Volt-Var functionality – Study (DEC System Off Peak)

Cases	Caps	Number of DER units	location	Control type	Control description	Gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #9	900 Kvar (head)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-172	-2412
case #9		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-97	
case #9		2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2143	
case #10	2400 Kvar (head), 900 Kvar (middle)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-170	-2432
case #10		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-115	
case #10		2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2147	
case #11	900 Kvar (head)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-170	-1671
case #11		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-122	
case #11		2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	No	1816	-1379	
case #12	1700 Kvar (head), 900 Kvar (middle)	2	head	Volt-Var	2% from 1.04 to 1.06	No	2000	-186	-1929
case #12		1	middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-195	
case #12		2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	Yes	1702	-1548	



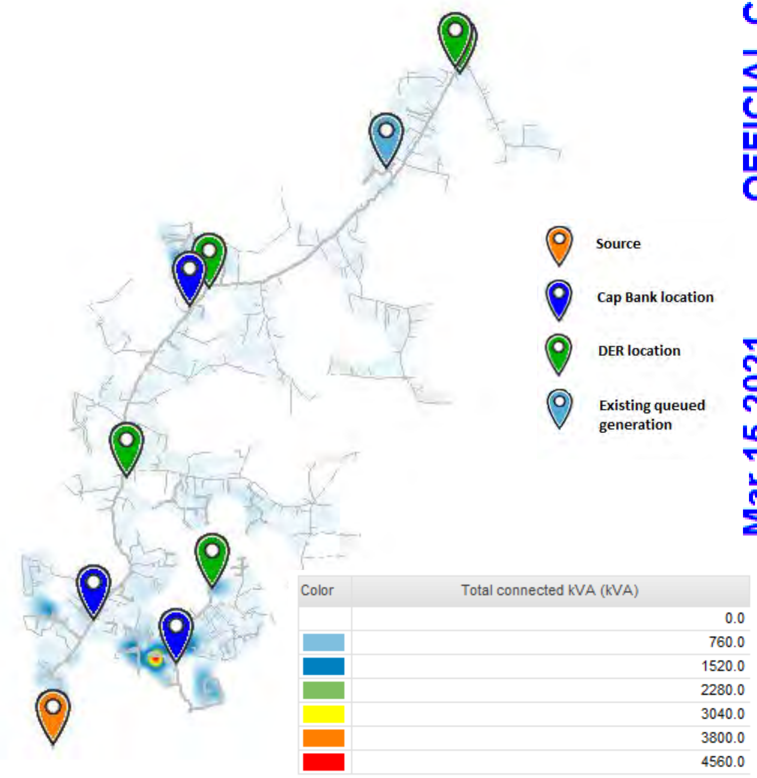
- Case #9 provides the most optimal response and reduce voltage below 1.05 pu.
- However, Case #9 has an 800 KVAR higher reactive requirement than Case #11.

Inverter Volt-Var functionality – Study (DEC System Shoulder Peak)

- Feeder description – Feeder A shoulder peak

Feeder load characteristics	Value
Total load KW	8879.7
Total load Kvar	2105.4
load PF	97.3%
Total load KVA	9125.9
Total KVA (peak load)	13735.6
Total load as a % of peak load	66.4%

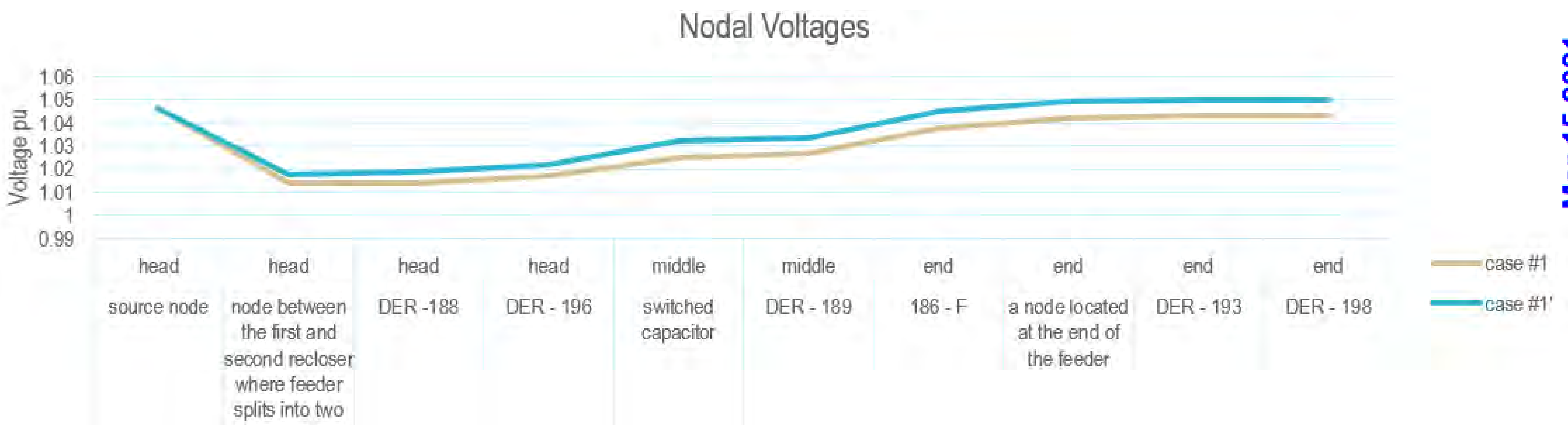
Generation*	Value
Existing queued generation (end of feeder)	336 KW
Generation with smart inverter capability modeled at the head section	4 MW
Generation with smart inverter capability modeled at the middle section	2 MW
Generation with smart inverter capability modeled at the end section	4 MW



Inverter Volt-Var Functionality – Study (DEC System Shoulder Peak)

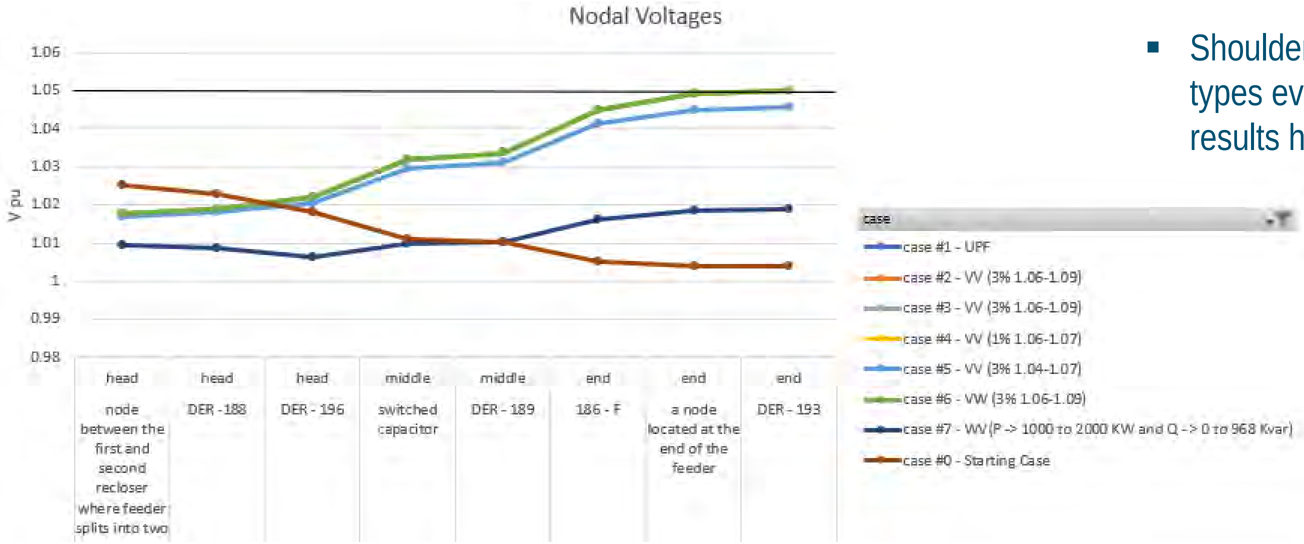
- Case Description – shoulder peak

Case	Caps	Regulator	Location	Control Type	Control Outline
case #1	offline	-5,-6,-4	head,middle and end	unity power factor	Unity power factor
case #1'	900 Kvar (head), 600 Kvar (head), 900 Kvar (middle)	-5,-6,-4	head,middle and end	unity power factor	Unity power factor



Inverter Volt-Var functionality – Study (DEC System Shoulder Peak)

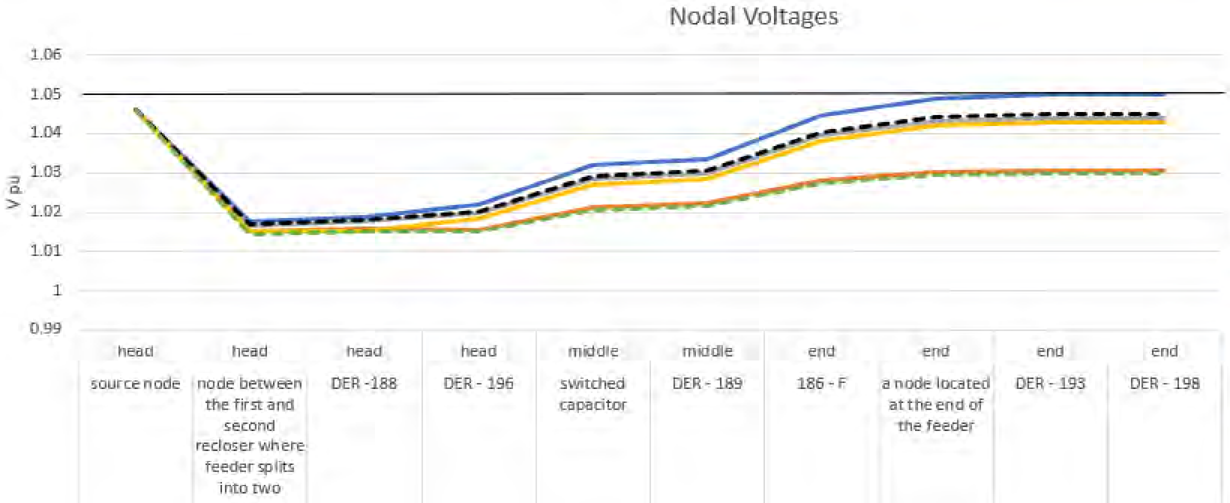
Case	Caps	Number of DER units	Location	Control type	Control description	gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #1	1500 Kvar (head), 900 Kvar (middle)	5	head,middle,end	Unity Power Factor	100%	No	2000	-170,-82,-158	-410
case #2, #3, #4	1500 Kvar (head), 900 Kvar (middle)	3	head,middle,end	Volt-Var	3% from 1.06 to 1.09	No	2000	-170,-82,-158	-410
case #5	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	3% from 1.04 to 1.07	No	2000	-170,-84	-826
case #5	1500 Kvar (head), 900 Kvar (middle)	2	end	Volt-Var	3% from 1.04 to 1.07	No	2000	-572	
case #6	1500 Kvar (head), 900 Kvar (middle)	5	head,middle,end	Volt-Watt	3% from 1.06 to 1.09	No	2000	-170,-82,-158	-410
case #7	1500 Kvar (head), 900 Kvar (middle)	5	head,middle,end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	--2162,-1079,-2158	-5399



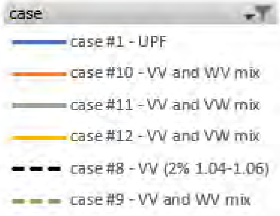
- Shoulder peak cases were tested for control types evaluated for the off-peak case to see if results hold true in the shoulder peak case

Inverter Volt-Var functionality – Study (DEC System Shoulder Peak)

Case	Caps	Number of DER units	location	Control type	Control description	Gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	Total_Kvar absorption at the PCC
case #8	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-170,-148	-978
case #8	1500 Kvar (head), 900 Kvar (middle)	2	end	Volt-Var	2% from 1.04 to 1.06	No	2000	-660	
case #9	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-172,-86	-2412
case #9	1500 Kvar (head), 900 Kvar (middle)	2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2154	
case #10	3900 Kvar (head), 900 (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-172,-86	-2412
case #10	3900 Kvar (head), 900 (middle)	2	end	Watt-Var	P->1000 to 2000 KW and Q->0 to 968 Kvar	Yes	2000	-2154	
case #11	1500 Kvar (head), 900 Kvar (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-170,-148	-978
case #11	1500 Kvar (head), 900 Kvar (middle)	2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	No	2000	-660	
case #12	2500 Kvar (head), 900 (middle)	3	head,middle	Volt-Var	2% from 1.04 to 1.06	No	2000	-170,148	-1030
case #12	2500 Kvar (head), 900 (middle)	2	end	Volt-Var and Volt-Watt	volt-var: 2% 1.04 to 1.06 and volt-watt - 2% 1.05 to 1.07	No	2000	-712	



- The results indicate, control setpoint picked for off-peak would work for shoulder-peak as well.
- The reactive compensation is also set by the off-peak case

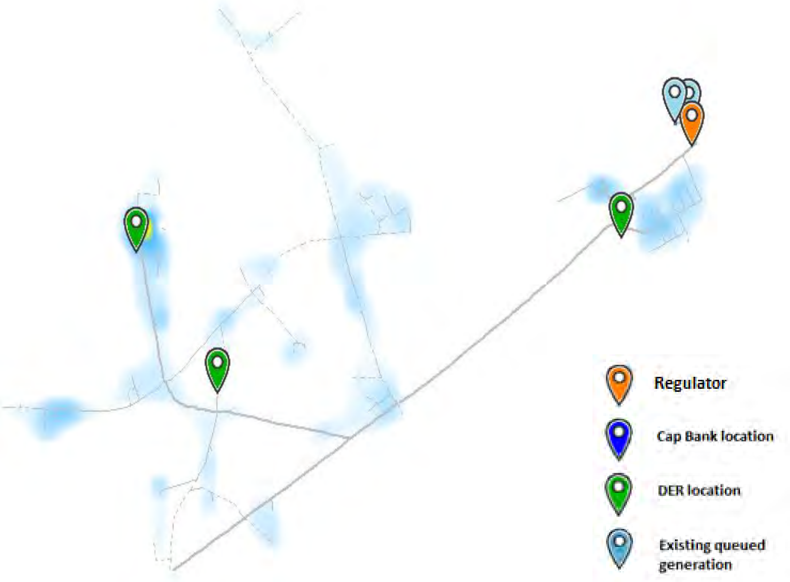


Inverter Volt-Var functionality - Study (DEP System Off-Peak)

- Feeder B description – off-peak

Feeder load characteristics	Value
Total load KW	252.2
Total load Kvar	94.7
load PF	94.0%
Total load KVA	269.4
Total KVA (peak load)	7103.8
Total load as a % of peak load	3.8%

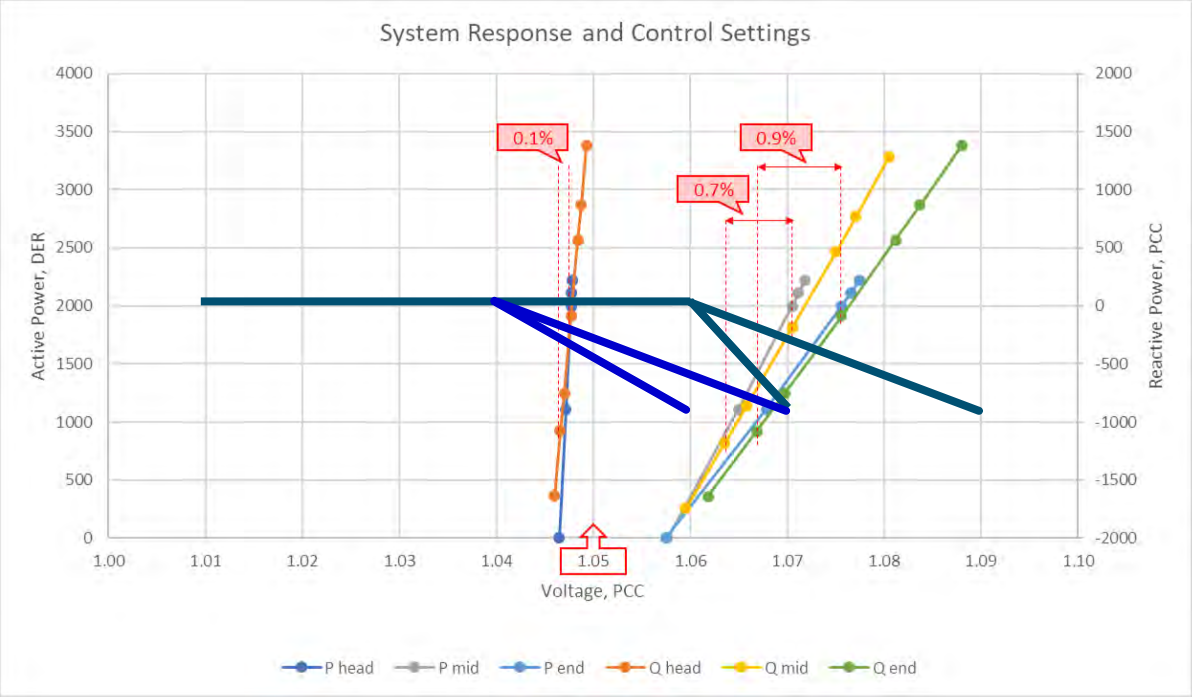
Generation*	Value
Existing queued generation (head of the feeder)	10 MW
Generation with smart inverter capability modeled at the head section	2 MW
Generation with smart inverter capability modeled at the middle section	2 MW
Generation with smart inverter capability modeled at the end section	2 MW



Color	Total connected kVA (kVA)
	0.0
Blue	178.3
Yellow	356.7
Red	535.0

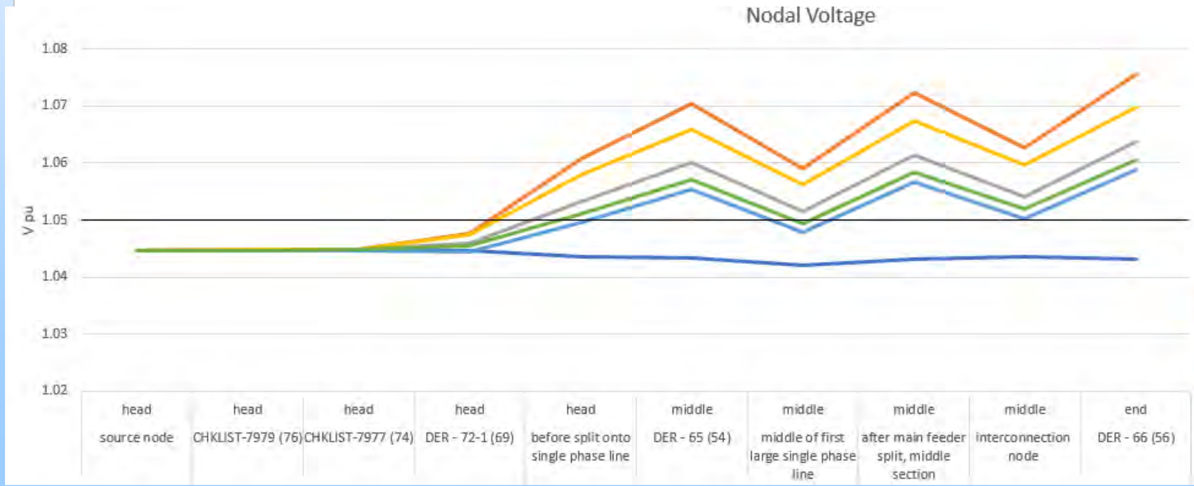
Application to Settings

- The response at the end of the feeder is similar to the previous circuit
- The response at the head is much lower
- The last two controllers are electrically close, that indicates similar controls should be effective
- Given the voltage at the head, the first DER is likely to operate absorbing
- The last two DER are expected to operate near reactive limit

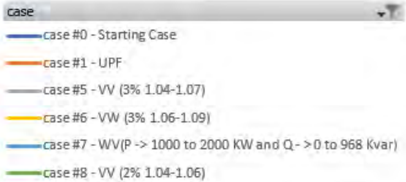


Inverter Volt-Var functionality – Study (DEP System Off-Peak)

Case	Caps	Number of DER units	Location	Control type	control outline	gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	total Kvar
case #1	none	3	head,middle,end	Unity Power Factor	Unity Power Factor	No	2000	-82,-78,-86	-246
case #5	none	1	head	volt-var	3% from 1.04 to 1.07	No	2000	-276	
case #5	none	1	middle	volt-var	3% from 1.04 to 1.07	No	1999	-744	-1897
case #5	none	1	end	volt-var	3% from 1.04 to 1.07	Yes	1999	-877	
case #6	none	1	head	volt-watt	3% from 1.06 to 1.09	No	2000	-82	
case #6	none	1	middle	volt-watt	3% from 1.06 to 1.09	No	1769	-63	-198
case #6	none	1	end	volt-watt	3% from 1.06 to 1.09	No	1490	-53	
case #7	none	3	head,middle,end	watt-var	P_1000->2000kW Q_0-928kVAR or 0.9 pf	Yes	2000	-1075,-1072,-1078	-3225
case #8	none	1	head	volt-var	2% from 1.04 to 1.06	No	2000	-347	
case #8	none	1	middle	volt-var	2% from 1.04 to 1.06	Yes	1999	-923	-2341
case #8	none	1	end	volt-var	2% from 1.04 to 1.06	Yes	1999	-1071	

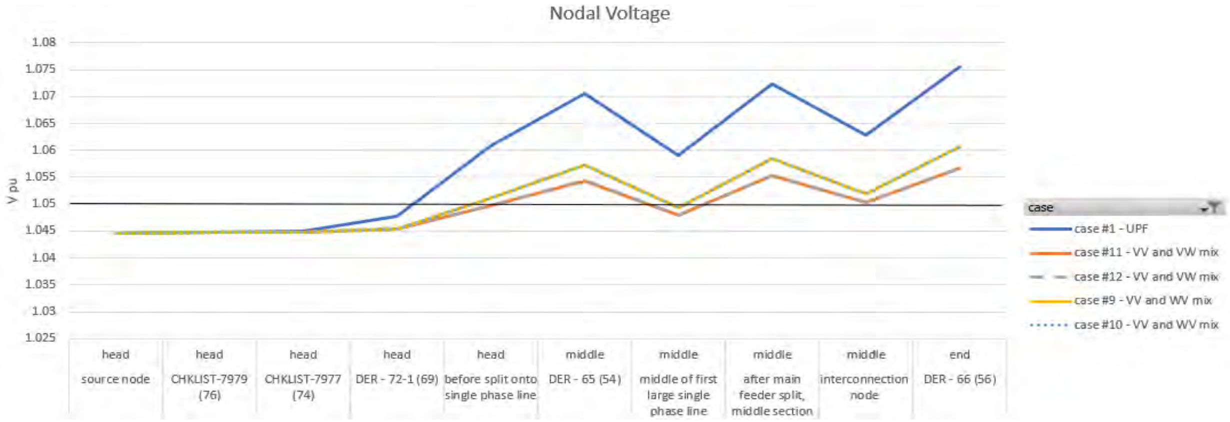


- Control setpoints evaluated for Feeder A were also evaluated for Feeder B. As expected, Case #7 reduces voltages the most but has a very high reactive power absorption. Case #8 has a better response.



Inverter Volt-Var functionality – Study (DEP System Off-Peak)

Case	Caps	Number of DER units	Location	control type	control outline	gen outside 0.95 pf limit	Inverter_KW	Kvar absorption at the PCC	total Kvar
case #9	none	1	head	volt-var	2% from 1.04 to 1.06	No	2000	-346	-2341
case #9	none	1	middle	volt-var	2% from 1.04 to 1.06	Yes	1999	-923	
case #9	none	1	end	watt-var	P_1000->2000kW Q_0-928kVAR or 0.9 pf	Yes	1999	-1072	
case #10	2400 Kvar (head)	1	head	volt-var	2% from 1.04 to 1.06	No	2000	-346	-2341
case #10	2400 Kvar (head)	1	middle	volt-var	2% from 1.04 to 1.06	Yes	1999	-923	
case #10	2400 Kvar (head)	1	end	watt-var	P_1000->2000kW Q_0-928kVAR or 0.9 pf	Yes	1999	-1072	
case #11	none	1	head	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	No	2000	-352	-1934
case #11	none	1	middle	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1679	-752	
case #11	none	1	end	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1449	-830	
case #12	2000 Kvar (head)	1	head	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	No	2000	-352	-1934
case #12	2000 Kvar (head)	1	middle	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1679	-752	
case #12	2000 Kvar (head)	1	end	volt-var and volt-watt	volt-var: 2% from 1.04 to 1.06 and volt-watt - 2% from 1.05 to 1.07	Yes	1449	-830	



- Case #9 and Case #11 have better voltage responses. Case #11 reduces active power, whereas Case#9 results in an additional 400 KVAR reactive power absorption as compared to Case #11.

Inverter Volt-Var functionality

- Summary of Results:
  - The control settings evaluated for Feeder A were also evaluated for Feeder B.
  - Study indicates a standalone volt-var controller is not sufficient to mitigate voltage issues for DER units at the end of the feeder. dP/dV and dQ/dV curves confirm this result as well.
  - dP/dV and dQ/dV curves also indicate limited voltage control would be available for units at the head of the feeder.
  - Volt-Var control in combination with Volt-Watt control or a standalone Watt-Var controller could work for units at the end of the feeder.
  - Universal controller could work:
    - Best controller for Feeder A off-peak would also work for Feeder A shoulder-peak and other loading conditions.
    - The same controller for Feeder A could work for Feeder B. Studies on additional feeders would give an indication on this.

Inverter Volt-Var functionality – Next Steps

- Incorporate stakeholder feedback into these first 2 feeders
- Set up the testing parameters for the remaining 4 feeders.
- Apply dV/dP and dV/dQ calculations in determining appropriate control methodology and control settings.
- For the optimized control settings determine approximate Var compensation magnitude and suggested source/equipment on high-level (if any needed) to maintain the power factor (or reactive power) at the feeder and bank level.
  - Provide reactive compensation equal to the reactive power absorbed at the DER PCC
- Evaluate if a universal controller is effective for all the circuits.
- Set the long-term dynamic profiles with the identified load and irradiance profiles and simulate test days with the optimized control settings.

Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting September 2, 2020

Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting

Anthony C Williams, P.E.
Principal Engineer
DER Technical Standards

September 2, 2020

DUKE ENERGY®

Agenda

- Review main revisions
  - Current version is “Duke Energy IEEE 1547 Implementation Guidelines, Rev 1”
- Next steps
- Discussion

Ground Rules

- All Stakeholder Group meetings, webinars and information exchange are designed solely to provide an open forum or means for the expression of various points of view in compliance with antitrust laws.
- Under no circumstances shall Stakeholder Group activities be used as a means for competing companies to reach any understanding, expressed or implied, which tends to restrict competition, or in any way, to impair the ability of participating members to exercise independent business judgment regarding matters affecting competition or regulatory positions.
- Proprietary information shall not be disclosed by any participant during any group meetings. In addition, no information of a secret or proprietary nature shall be made available to Stakeholder Group members.
- All proprietary information which may nonetheless be publicly disclosed by any participant during any group meeting shall be deemed to have been disclosed on a non-confidential basis, without any restrictions on use by anyone, except that no valid copyright or patent right shall be deemed to have been waived by such disclosure.

DUKE ENERGY

Logistics

- Clarifying questions will be answered during the presentation and stakeholder discussions at the end of the presentation
- Written feedback and comments will be solicited using comment form
  - Note questions then lets discuss – don't really want all the questions sent in that are mainly just for clarification – this takes a lot of time to address that could be spent on the comments and recommendations
  - It would be helpful to provide more Comment and Proposed Change details :

Stakeholder Name	Page Number	Paragraph Number	Comment	Proposed Change
example Question format	3	2	Why is winter data excluded?	None
example Comment format	7	4	Agree with the hours of study.	None
example Comment format	7	4	'the largest' is not clear	Replace 'the largest' with 'the maximum of the three pha[se] currents"
example Recommendation format	10	3	The types of faults is too limited. Include single line to ground faults.	Include SLG faults

  - Being more specific makes the point, or main concerns, of the comment more apparent and allows a more direct response.
- Comments will be taken during the discussion and the form will be distributed after the meeting
- Share the feedback form using email: Duke-IEEE1547@duke-energy.com for stakeholders to provide their written feedback

Priority Groups 1 – 5 Review

1st	• Reactive power and voltage control • Power quality
2nd	• Voltage tripping and ride through • Frequency tripping and ride through
3rd	• Most important sections of Section 4, General Tech Specs
4th	• Most commonly applied sections of Section 4, General Tech Specs
5th	• Remaining sections of Section 4, General Tech Specs

DUKE ENERGY

Priority Table Updates, Group 1

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
1 (DUK-01)	5.2	Reactive power capability of the DER	Category B 35° C ambient or higher at rated voltage	No Reqmt	Eval + Comm Test
1 (DUK-02)	5.3	Voltage and reactive power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-03)	5.4.2	Voltage-active power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-04)	7.4	Limitation of overvoltage contribution	Accept 1547 with additional requirements~~Pending. Likely requires more industry experience or analysis to address this issue~~	TBD	Eval + Comm Test
1 (DUK-05)	7.2.3	Power Quality, Flicker	Accept 1547 in conjunction with continued use of IEEE 1453~~Continue existing criteria and policy~~	No Reqmt	Eval + Comm Test
1 (DUK-06)	7.2.2	Power Quality, Rapid voltage change (RVC)	Continue existing criteria and policy	TBD	Eval + Comm Test

DUKE ENERGY

Priority Table Updates, Group 2

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
2 (DUK-07)	6.4.1	Mandatory voltage tripping requirements (OV/UV)	Have existing setpoints; new 1547 setpoint study in progress ~~TBD~~	TBD	Eval + Comm Test
2 (DUK-08)	6.5.1	Mandatory frequency tripping requirements (OF/UF)	Have existing setpoints; new 1547 setpoint study in progress ~~setpoints TBD~~	TBD	Eval + Comm Test
2 (DUK-09)	6.4.2	Voltage disturbance ride-through requirements	Study in progress	TBD	Eval + Comm Test
2 (DUK-10)	6.5.2	Frequency disturbance ride-through requirements	Study in progress	TBD	Eval + Comm Test
2 (DUK-11)	6.5.2.7	Frequency-droop (frequency-power) capability	~~TBD~~Evaluation has not begun	No Reqmt	Eval + Comm Test
2 (DUK-12)	6.5.2.6	Voltage phase angle changes ride-through	Study in progress~~TBD~~	No Reqmt	Eval + Comm Test
3 (DUK-13)	4.5	Cease to energize performance requirement	Accept 1547 as written	Yes	Eval + Comm Test

Priority Group 1 Revisions

- DUK-05 Section 7.2.3 – Flicker, ready to be implemented

> Duke Energy adopts these requirements as written in the Standard. Note that Duke also applies IEEE 1453 recommended practices.

- DUK-04 Section 7.4 – Limitation of overvoltage contribution, ready to be implemented.

> Duke Energy adopts these requirements as written in the Standard. The industry has found that the inverter designs are reaching and exceeding the harmonic monitoring capabilities of existing measurement devices. Therefore, Duke Energy requires the DER owner to mitigate all order harmonics to no greater than 0.3% if the harmonics affect other customers. Harmonic limits shall be aggregated and applied during the DER hours of operation.

Priority Group 2 Revisions

- DUK-17 Section 4.2 – Reference points of applicability (RPA)

The final position must consider the variety of RDER and UDER interconnections and identify the RPA for each. In practice, the interconnections have been very straightforward. The default RPA is the PCC. The RPA for UDER is the PCC (point of common coupling at the utility interconnection point) and the PoC (point of connection) is the RPA for the net meter installations. The approved UDER transformer connections all maintain zero sequence continuity.

- DUK-07 Section 6.4.1 – Mandatory voltage tripping requirements

Consensus was reached with Transmission System Planning and Operations for POI Recloser voltage and frequency settings and time delays that provide adequate ride-through for BES events. The team is still reviewing the impact to system protection with the proposed settings.

- Several sections have Verification and test requirements updates

Priority Group >5 Updates

- DUK-112 Section 10.3, 10.4 – Nameplate and configuration information

These sections address the two broad types of information available through the local DER communication interface. The following terms are listed in decreasing order of magnitude. The value of each parameter in the list is greater than or equal to the value of the parameter below it: Nameplate Apparent Power Maximum Rating Configuration Apparent Power Maximum Rating Nameplate Active Power Rating (unity power factor) Configuration Active Power Rating (unity power factor)
The list above does not address all the terms in the table. Such a specification is not necessary of every term, but helpful to clarify for some. Duke will consider addressing other terms as needed. Consequently, operational limits and settings, such as the Active Power Limit, cannot be greater than the ratings (not applicable to abnormal or protection settings).

Recommended Next Steps

- Awaiting further information from the ongoing study by Protection and Transmission Planning groups
- Continue with the inverter reactive power control studies
- Maintain focus on the Priority groups 1 and 2
- Additional thoughts?

Discussion

- Stakeholder input on the guidelines
- Sections Completed
  - DUK-05 Section 7.2.3 – Flicker
  - DUK-04 Section 7.4 – Limitation of overvoltage contribution
  - --- Previously ---
  - DUK-01 Section 5.2 – Reactive power capability of the DER

TSRG: Inverter Volt-VAR Study Scope Review
September 2, 2020

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

TSRG: Inverter Volt-VAR Study Scope Review

Anthony C Williams, DER Technical Standards

September 2, 2020

DUKE ENERGY®

Logistics

- Clarifying questions will be answered during the presentation; major discussions at the end
- Written feedback and comments will be solicited using comment form
  - Note questions then lets discuss – don't really want all the questions sent in that are mainly just for clarification – this takes a lot of time to address that could be spent on the comments and recommendations
  - It would be helpful to provide more Comment and Proposed Change details :

Stakeholder Name	Page Number	Paragraph Number	Comment	Proposed Change
example Question format	3	2	Why is winter data excluded?	None
example Comment format	7	4	Agree with the hours of study.	None
example Comment format	7	4	'the largest' is not clear	Replace 'the largest' with 'the maximum of the three pha[...] currents"
example Recommendation format	10	3	The types of faults is too limited. Include single line to ground faults.	Include SLG faults

response.

- Comments will be taken during the discussion and the form will be distributed after the meeting
- Share the feedback form using email: Duke-IEEE1547@duke-energy.com for stakeholders to provide their written feedback

Inverter Volt-VAR Study Overview

- North Carolina Commission had tasked Duke to evaluate software-based controls of advanced inverters according to IEEE 1547-2018 standard.
- Evaluate the use of autonomous voltage-reactive power control functions at multiple inverter-based distributed energy resources connected to the same feeder. Understand whether and how these controls cooperate with existing integrated voltage and VAR control systems.
- Evaluate the benefit and effectiveness of distributed voltage-reactive power controls at the distribution feeder level.
- Evaluate mitigation options required at the distribution feeder level to meet transmission imposed requirements for reactive power

First Study Recommended Next Steps

- Conduct time series power flow studies to look at system response over many hours
- Voltage controller concerns
  - With the IVVC commitments, how will those controls manage DER reactive power if something other than a fixed pf is used
  - Consider how to control the feeder head compensation capacitor with autonomous controls
  - Impact on feeders with regulators that use resistive drop compensation; could require significant feeder changes if the drop compensation is removed to accommodate DER reactive power control
  - Use the time series to investigate how well the existing voltage control device controllers manage the DER reactive power
- Consider controls that get more var absorption to hold voltage under 1.05
- Review the impact of higher var absorption on the feeders (closer examination of reactive power flow on the feeder)
- Consider pf based controls for voltage independence and voltage reference to absorb less reactive power at steady state
- Identify potential pilot sites; following further clarification from the additional steps above

Second Study Overview

- Expand the attributes monitored during the study; to inform conclusions
- Calculate P and Q responses
- Quasi-Static Time Series (QSTS) simulation using 8760 hourly load and solar profile
- Consider a broader variety of controller types
  - Limited controller setting variations: approximately 6 volt-var, 8 pf, 5 watt-var
  - Continued use of volt-watt to backup the primary controller
- More emphasis on higher voltage feeders so that less DER forces the overvoltage
- Compare monitored attributes across the feeders for the various controller types
  - Inform policy development to guide application of DER voltage and reactive power controls, and
  - Develop methods to a) provide a quick assessment of reactive power control effectiveness at a potential UDER interconnection point, and b) indicate the most appropriate type of control
- Interim update at October TSRG
- Final report February, presentation at the following TSRG

DUKE ENERGY®

*BUILDING A **SMARTER** ENERGY FUTURE*℠

Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting
October 28, 2020

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting

Anthony C Williams, P.E.
Principal Engineer

DER Technical Standards

October 28, 2020

DUKE ENERGY®

Agenda

- Review main revisions
  - Current version is "Duke Energy IEEE 1547 Implementation Guidelines, Rev 2"
    - Rev 1A is the redline version of Rev 2
- Discussion

Logistics

- Clarifying questions will be answered during the presentation and stakeholder discussions at the end of the presentation
- Written feedback and comments will be solicited using comment form
  - Note questions then lets discuss – don't really want all the questions sent in that are mainly just for clarification – this takes a lot of time to address that could be spent on the comments and recommendations
  - It would be helpful to provide more Comment and Proposed Change details :

Stakeholder Name	Page Number	Paragraph Number	Comment	Proposed Change
example Question format	3	2	Why is winter data excluded?	None
example Comment format	7	4	Agree with the hours of study.	None
example Comment format	7	4	'the largest' is not clear	Replace 'the largest' with 'the maximum of the three phase currents"
example Recommendation format	10	3	The types of faults is too limited. Include single line to ground faults.	Include SLG faults

  - Being more specific makes the point, or main concerns, of the comment more apparent and allows a more direct response.
- Comments will be taken during the discussion and the form will be distributed after the meeting
- Share the feedback form using email: Duke-IEEE1547@duke-energy.com for stakeholders to provide their written feedback

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority Groups 1 – 5 Review

1st	• Reactive power and voltage control • Power quality
2nd	• Voltage tripping and ride through • Frequency tripping and ride through
3rd	• Most important sections of Section 4, General Tech Specs
4th	• Most commonly applied sections of Section 4, General Tech Specs
5th	• Remaining sections of Section 4, General Tech Specs

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority Table Updates, Group 1

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
1 (DUK-01)	5.2	Reactive power capability of the DER	Category B 35° C ambient or higher at rated voltage	No Reqmt	Eval + Comm Test
1 (DUK-02)	5.3	Voltage and reactive power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-03)	5.4.2	Voltage-active power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-04)	7.4	Limitation of overvoltage contribution	Accept 1547 with additional requirements	No Reqmt	Eval + Comm Test
1 (DUK-05)	7.2.3	Power Quality, Flicker	Accept 1547 in conjunction with continued use of IEEE 1453	No Reqmt	Eval + Comm Test
1 (DUK-06)	7.2.2	Power Quality, Rapid voltage change (RVC)	Continue existing criteria and policy	TBD	TBD, Eval + Comm Test

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority Table Updates, Group 2

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
2 (DUK-07)	6.4.1	Mandatory voltage tripping requirements (OV/UV)	Have existing setpoints; new 1547 setpoint study in progress	TBD	Eval + Comm Test
2 (DUK-08)	6.5.1	Mandatory frequency tripping requirements (OF/UF)	Have existing setpoints; new 1547 setpoint study in progress	TBD	Eval + Comm Test
2 (DUK-09)	6.4.2	Voltage disturbance ride-through requirements	Study in progress	TBD	Eval + Comm Test
2 (DUK-10)	6.5.2	Frequency disturbance ride-through requirements	Study in progress	TBD	TBD, Eval + Comm Test
2 (DUK-11)	6.5.2.7	Frequency-droop (frequency-power) capability	Evaluation has not begun	No Reqmt	TBD, Eval + Comm Test
2 (DUK-12)	6.5.2.6	Voltage phase angle changes ride-through	Study in progress	No Reqmt	TBD, Eval + Comm Test

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority Group 1 Revisions

- All completed except the two associated with the voltage and reactive power control studies

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Priority Groups 2, 3, 4 Revisions

- DUK-13 Section 4.5 – Cease to energize performance requirement, ready to be implemented

Duke Energy requires cease to energize capability (not delivering power during steady-state or transient conditions) in accordance with the Standard.

~~For UDER, Duke Energy is still considering implementing the cease to energize at the inverter or disconnecting at the local EPS.~~

A DER can be directed to cease to energize and trip by changing the Permit service setting to "disabled" as described in IEEE 1547 subsection 4.10.3.

Interoperability requirements: No specific requirements for this section.~~The Binary Output is sent via SCADA to open inverter(s) breaker and is already implemented.~~

Priority Group >5 Updates

- DUK-26 Section 4.12 – Integration with Area EPS grounding, ready to be implemented

Duke accepts the Standard; that the grounding scheme of the DER interconnection shall be coordinated with the ground fault protection of the Area EPS. Duke's system is multi-grounded and the DER facilities and design must be compatible with the EPS. Each interconnection is reviewed for ground fault protection and for limiting the potential for creating over-voltages on the Area EPS.

Approved distribution connected utility scale DER transformer winding configurations are listed below:

Primary Winding Type (HV)	Secondary Winding Type (LV)	Zero Seq Maintained PCC to POC	Allowed for DER Interconnection	
			Inverter	Rotating
Wye-grounded	Wye-grounded	Yes, (w/4-wire LV)	Yes	Yes
Wye-grounded	Wye	No	Yes	No
Wye-grounded	Delta	No	No	Yes

DUKE ENERGY

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Summary

- Sections accepted as written in 1547
  - DUK-28 Section 4.8 – Isolation device
  - DUK-23 Section 4.9 – Inadvertent energization of the Area EPS
  - DUK-29 Section 4.11.1 – Protection from electromagnetic interference
  - DUK-30 Section 4.11.2 – Surge withstand performance
  - DUK-22 Section 4.11.3 – Paralleling device
- Sections completed
  - DUK-13 Section 4.5 – Cease to energize performance requirement
  - DUK-26 Section 4.12 – Integration with Area EPS grounding, ready to be implemented

  --- Sections previously completed ---

  - DUK-05 Section 7.2.3 – Flicker
  - DUK-04 Section 7.4 – Limitation of overvoltage contribution
  - DUK-01 Section 5.2 – Reactive power capability of the DER

Discussion

- Maintain focus on the Priority groups 1 and 2
  1. Continue with the inverter reactive power control studies
  2. Await conclusions from the ongoing study by the Protection and Transmission Planning groups
- Collect stakeholder input on the guidelines

DUKE ENERGY®

TSRG: Inverter Volt-VAR Study Update
October 28, 2020

TSRG: Inverter Volt-VAR Study Update

Anthony C Williams, DER Technical Standards

October 28, 2020

DUKE ENERGY®

Second Study Overview

- More emphasis on higher voltage feeders so that less DER forces the overvoltage
- Calculate P and Q responses
- Consider a broader variety of controller types
  - Limited controller setting variations: approximately 6 volt-var, 8 pf, 5 watt-var
  - Continued use of volt-watt to backup the primary controller
- Expand the attributes monitored during the study; to inform conclusions
- Quasi-Static Time Series (QSTS) simulation using 8760 hourly load and solar profile
- Compare monitored attributes across the feeders for the various controller types
  - Inform policy development to guide application of DER voltage and reactive power controls, and
  - Develop methods to a) provide a quick assessment of reactive power control effectiveness at a potential UDER interconnection point, and b) indicate the most appropriate type of control
- Interim update at October TSRG
- Final report February, presentation at the following TSRG

Feeder Selection

- Attributes that may indicate feeders more relevant for volt-VAR studies
  - Initial system voltage near voltage limit
  - Short circuit MVA at the PCC – low, typical, high
  - DER kW on the feeder (not penetration)
  - Upstream voltage regulation devices with droop compensation
- Weighted
- Sorted by feeders with the highest value

P and Q responses

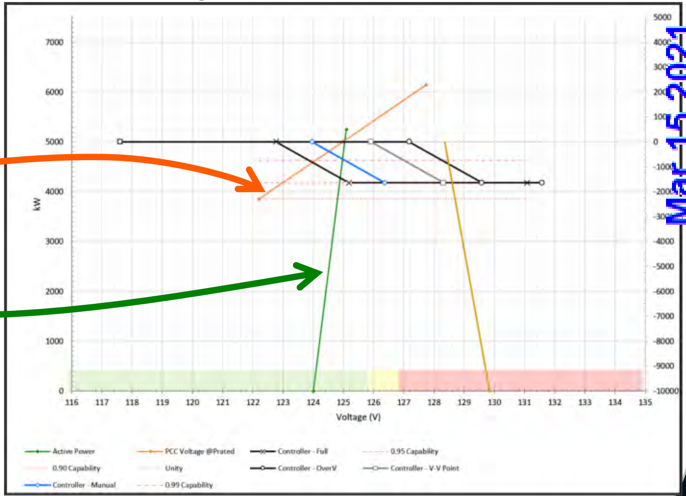
1. Using data from a few operating points

(- means sending to grid)	PCC Voltage			PCC		Inverter	
	A	B	C	P	Q	P	Q
P=0S, Q=0S	126.1	125.8	125.7	0	0	0	0
P=1S, Q=0S	127	126.7	126.6	-5020	254	-5040	0
P=0.9S, Q=-0.44S	124	123.7	123.6	-4514	2475	-4536	2196
P=0.9S, Q=0.44S	129.8	129.5	129.4	-4517	-1964	-4536	-2198

2. Several characteristics of the feeder can be determined

kVA	5040
Presp = dV/Psys	0.15%
Pctrl = dV/Prated	0.68%
dV/Prated	0.81
Qresp = dV/Qsys	1.13%
Qctrl = dV/Qrated	2.47%
dV/Qrated	2.97
Qresp/Presp	7.53
Qrated/Prated	*3.65*
Q/P OV	*9.05*
SCC	86.2
X	1.15
X/R	6.23

3. To assist with evaluating the initial settings



Sample of Controller Configurations

- power factor control (pf)
  - Baseline options
    - 1.0 pf (0%)
    - 0.95 pf (31%)
    - 0.90 pf (44%)
  - Full compensation (offset voltage change at Prated)
  - Overvoltage compensation (offset overvoltage at Prated)
    - A good limiting case, but probably not a practical case
  - Likely adding a few more pf points across the range of interest will be most useful; provide a common baseline
    - 0.97 (24%)
    - 0.98 (20%)
    - 0.99 (14%)

Sample of Controller Configurations

- voltage – reactive power control (v-var)
  - Baseline options
    - IEEE default A and B
    - Study 1 setting, 1.04 pu, 2% slope to Qrated
  - Continue the Boundary cases
    - Full compensation (offset voltage change at Prated)
    - Overvoltage compensation (offset overvoltage at Prated)
  - Considering other standardized controls, for example
    - A setting that exhausts reactive capability at voltage limit
    - May adopt a standard range here too, like with pf
      - Spread the settings across a range: 1.02, 1.03, and 1.04.

Sample of Controller Configurations

- active power control – reactive power control (watt-var)
  - Baseline options
    - Use a pf control
    - IEEE default A and B
  - Continue the Boundary cases
    - Full compensation (offset voltage change at Prated)
    - Overvoltage compensation (offset overvoltage at Prated)
  - Consider variations that delay reactive compensation until higher active power levels

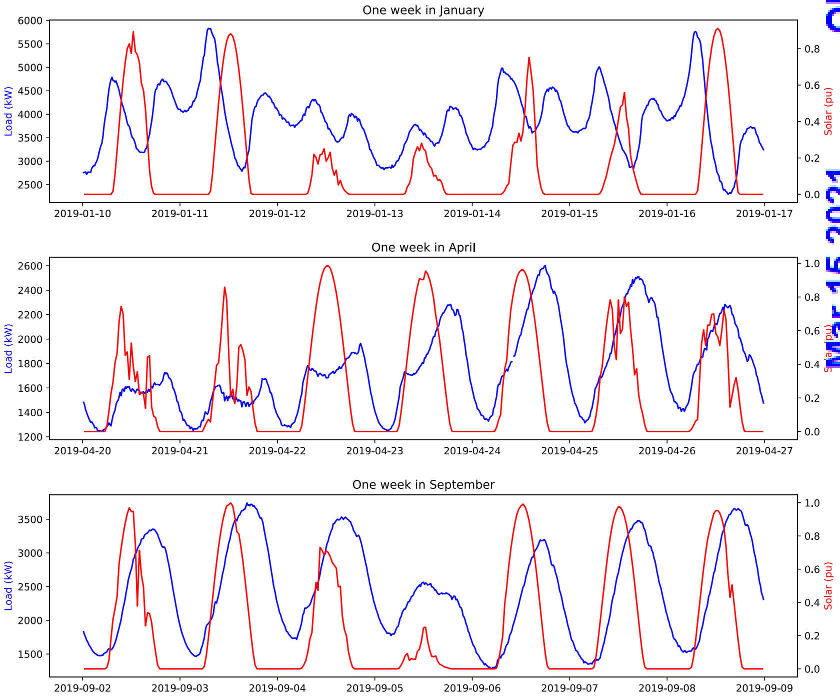
- voltage – active power control (v-watt)
  - Settings from first study: 1.06 puV, 0 puQ : 1.09puV, -0.312 puQ
  - Expect to use it as a secondary to the primary controller, except for
  - May use at feeder head DER locations where reactive power is not effective

Metrics

- Site specific (fixed)
  - Rated Pgen, Qgen at PCC and inverter
  - SCC at Station, PCC
  - X, from PCC back to source
  - R, from PCC back to source
  - PCC Voltage, Basecase (P=Q=0)
  - PCC Voltage, Initial (P=Prated, Q=0)
  - Min load kva/Peak load kva
  - Feeder head power flow, kW and kVAR
  - ΔV/ΔP (Presp, derivative of voltage variation to real power injection)
  - ΔV/ΔQ (Qresp, derivative of voltage variation to reactive power injection)
  - Qresp/Presp = (dV/dQ) / (dV/dP)
  - ΔV/ΔPrated (total voltage change at rated active power)
  - ΔV/ΔQrated (total voltage change at rated reactive power)
- Controller specific
  - Overvoltage Magnitude, PCC, Feeder, Inverter (V)
  - Overvoltage Occurrences, PCC, Feeder, Inverter
  - Feeder Active Power Max, Min (kW)
  - Feeder Reactive Power, Max, Min (kVAR)
  - Total MWh, MVARh, at PCC, Inverter
  - Tradeoff MW, MWh

Quasi-Static Time Series (QSTS) Model

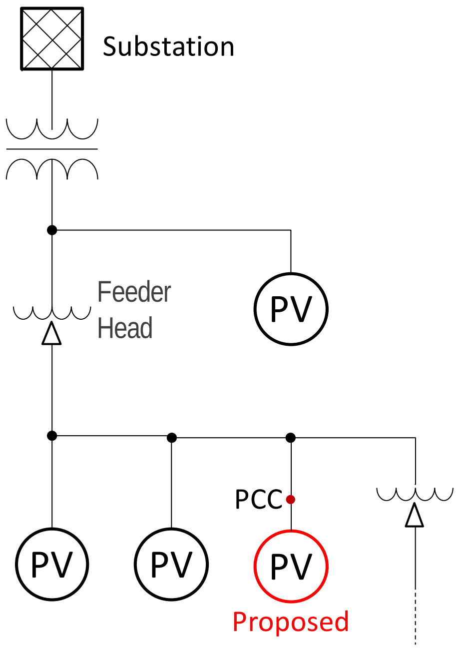
- 8760-hour load profile developed from DEC and DEP measurements (for year 2019)
- Solar taken from the NREL NSRDB database (at each feeder zip code and for year 2019)
- Feeder voltage regulation (e.g., LTC, VR, CB)
  - Local control as in the original CYME models
- Inverter control
  - Q priority (i.e., active power restricted if needed)
  - Q cut-in power level = 5% of inverter rating
- Baseline case definition
  - No injection from the PV under study while all other existing PVs generate power
- Smart Inverter functions in evaluation
  - Constant Power Factor
  - Volt-Var
  - Watt-Var



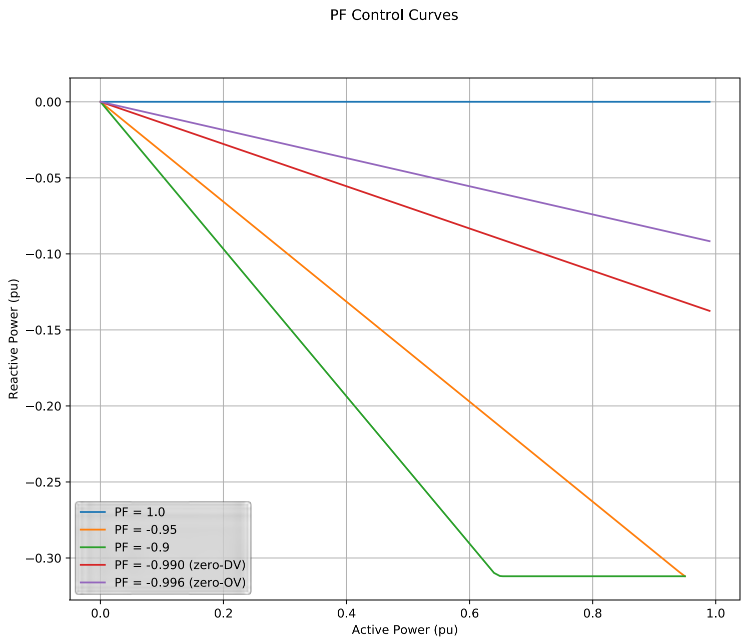
Time Series Preliminary Results

Feeder A Characterization Table

Parameter	Value
Feeder peak load	6.85 MW (PF = 0.995)
Connected DERs	Three existing and one proposed (5.5MVA each)
R_PCC (pu @ 1MVA)	0.0018
X_PCC (pu @ 1MVA)	0.011
∂V / ∂P (puV / 1MW)	0.0014 (-0.0005 ~ 0.0014 depending on load/gen levels)
∂V / ∂Q (puV / 1MVAr)	0.0110 (0.0105 ~ 0.0110 depending on load/gen levels)



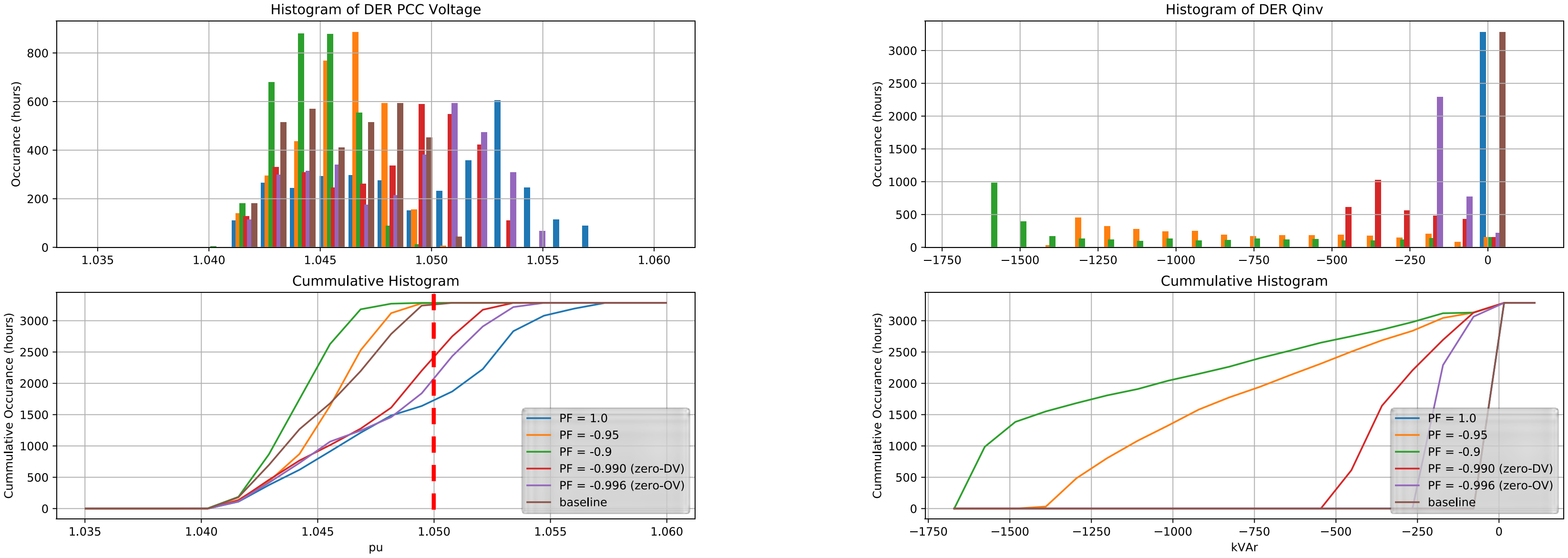
Constant Power Factor Control Mode Comparison



	PF=1.0	PF=-0.95	PF=-0.9	PF=-0.990 (zero-DV)	PF=-0.996 (zero-OV)
Max V_PCC (pu)	1.058	1.050	1.049	1.054	1.055
DER MWh	8472	8465	8459	8472	8472
DER MVArh	0	-2775	-3798	-1173	-782
Max Tradeoff MW	0.0	0.2	0.3	0.0	0.0
Tradeoff MWh	0.2	7.6	14.7	0.4	0.2
Feeder Loss MWh	268 +179	268 +176	268 +178	268 +176	268 +177
Feeder Loss MVArh	2517 +1573	2517 +1596	2517 +1625	2517 +1569	2517 +1568

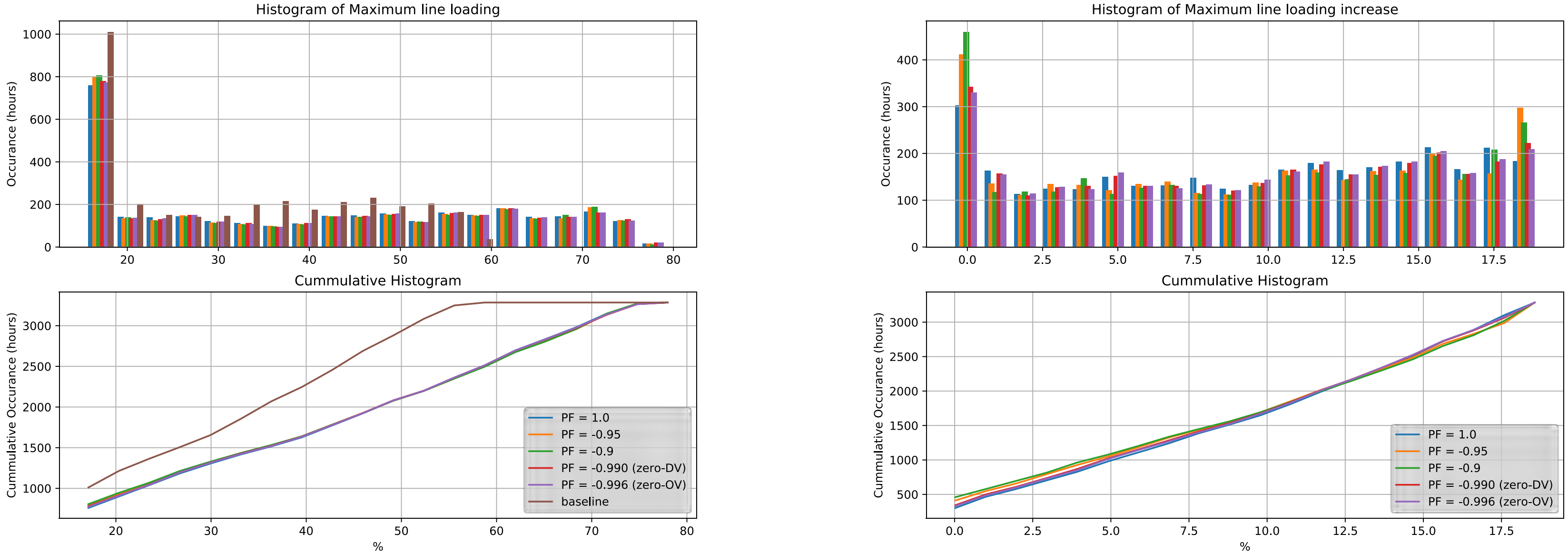
- Inverter clamps Q at 31.2% as its specified limit (equivalent to 0.95 power factor)
- The worst-case (PF=-0.9) tradeoff MWh is 0.17% (i.e., 14.7MWh/8472MWh) of the total generation yield
- The difference between control modes on feeder loss is insignificant

Constant Power Factor Control Mode (Continue)



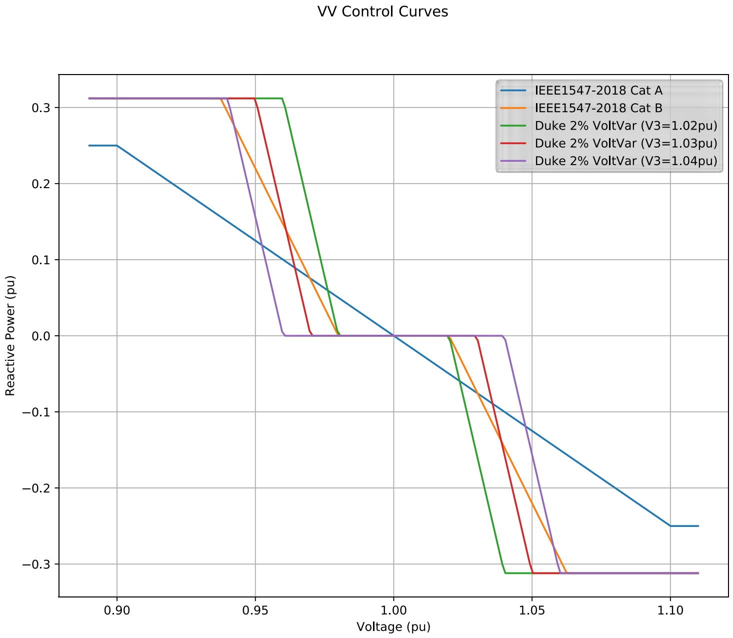
- Only 9AM to 5PM daily hours for 365 days
- Baseline case means no power output from the proposed DER
- Zero-DV power factor still sees over-voltage due to the operation of line voltage regulator
- As power factor becomes more inductive, so does the absorbed Q increase

Constant Power Factor Control Mode (Continue)



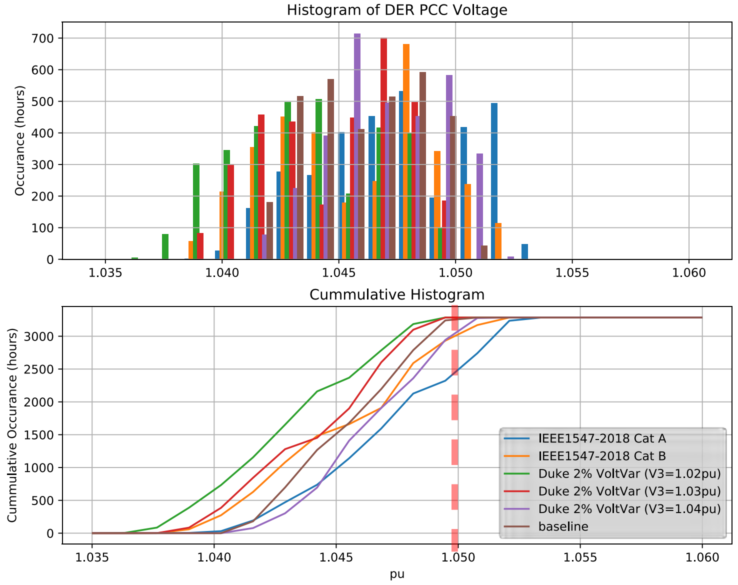
- All power factor modes show similar increase (~17%) to the maximum line loading
- No over-loading is observed in this feeder due to the proposed DER

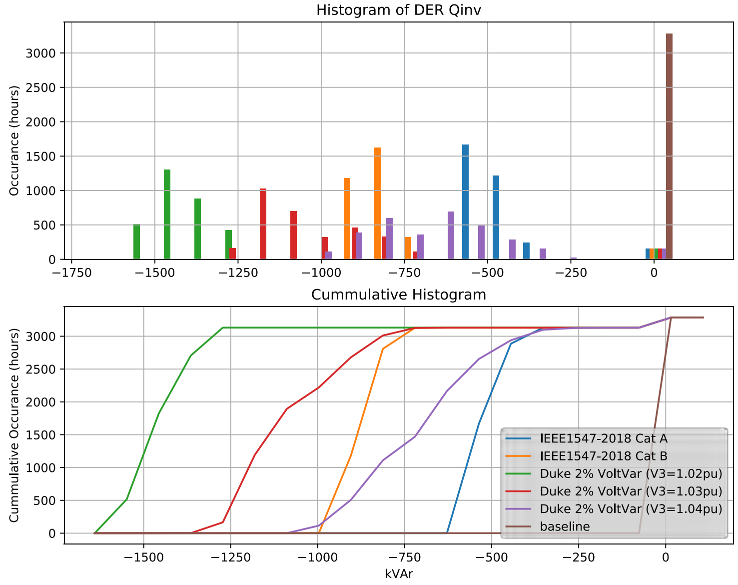
Volt-Var Control Mode



	1547 A	1547 B	2% V3=1.02	2% V3=1.03	2% V3=1.04
Max V_PCC (pu)	1.053	1.052	1.049	1.050	1.052
DER MWh	8472	8471	8466	8468	8472
DER MVArh	-1862	-2956	-4831	-3614	-1869
Max Tradeoff MW	0.0	0.1	0.2	0.2	0.1
Tradeoff MWh	0.3	1.6	7.1	4.4	0.8
Feeder Loss MWh	268 +174	268 +174	268 +177	268 +175	268 +175
Feeder Loss MVArh	2517 +1557	2517 +1571	2517 +1617	2517 +1591	2517 +11566

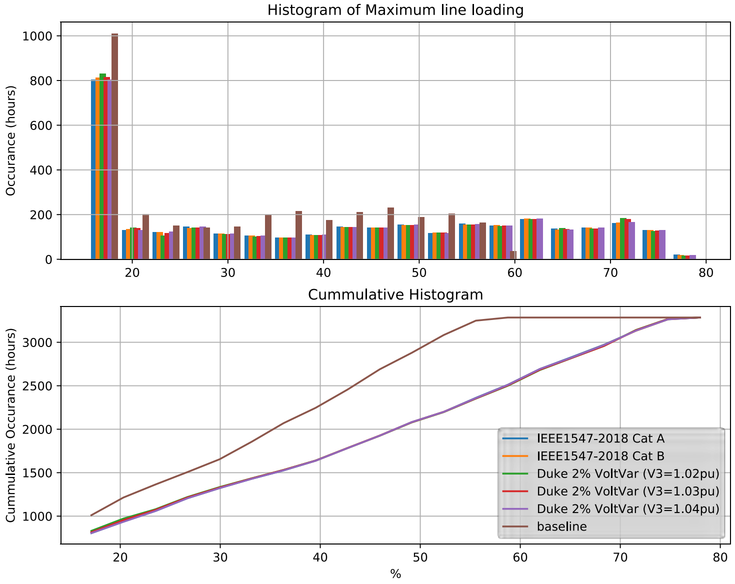
Volt-Var Control Mode (Continue)

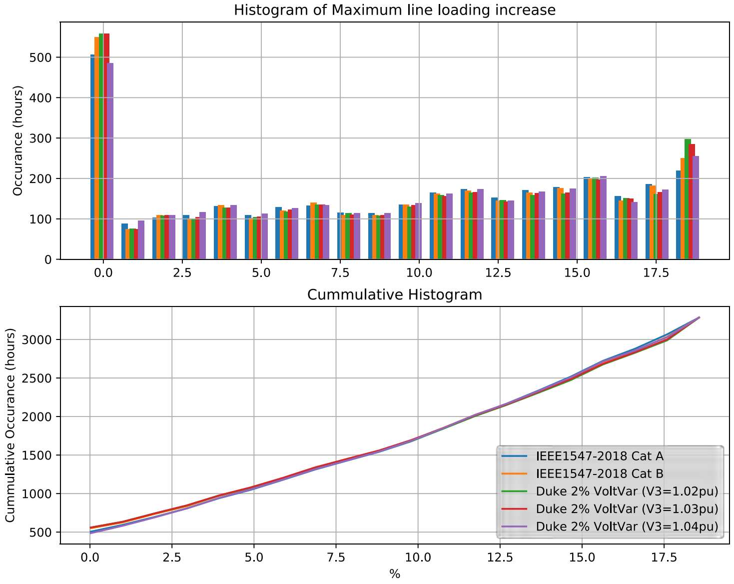




- Most options show lower number of over voltage hours as compared to power factor mode
- Earlier voltage regulation (V3=1.02 or 1.03) helps mitigate over voltage violation
- Steeper volt-var slope helps mitigate over voltage violations (1547-B vs. 2%-V3=1.02)

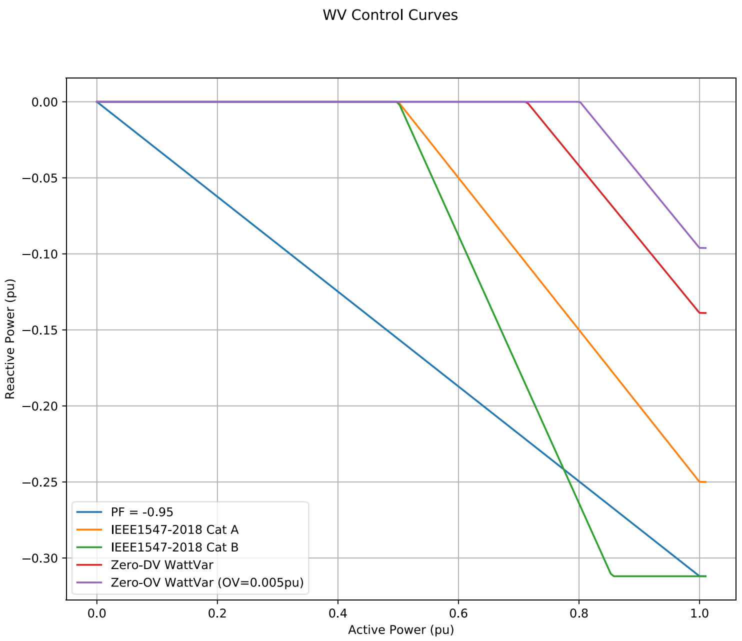
Volt-Var Control Mode (Continue)





- All options show similar increase (~17%) to the maximum line loading
- No over-loading is observed in this feeder due to the proposed DER

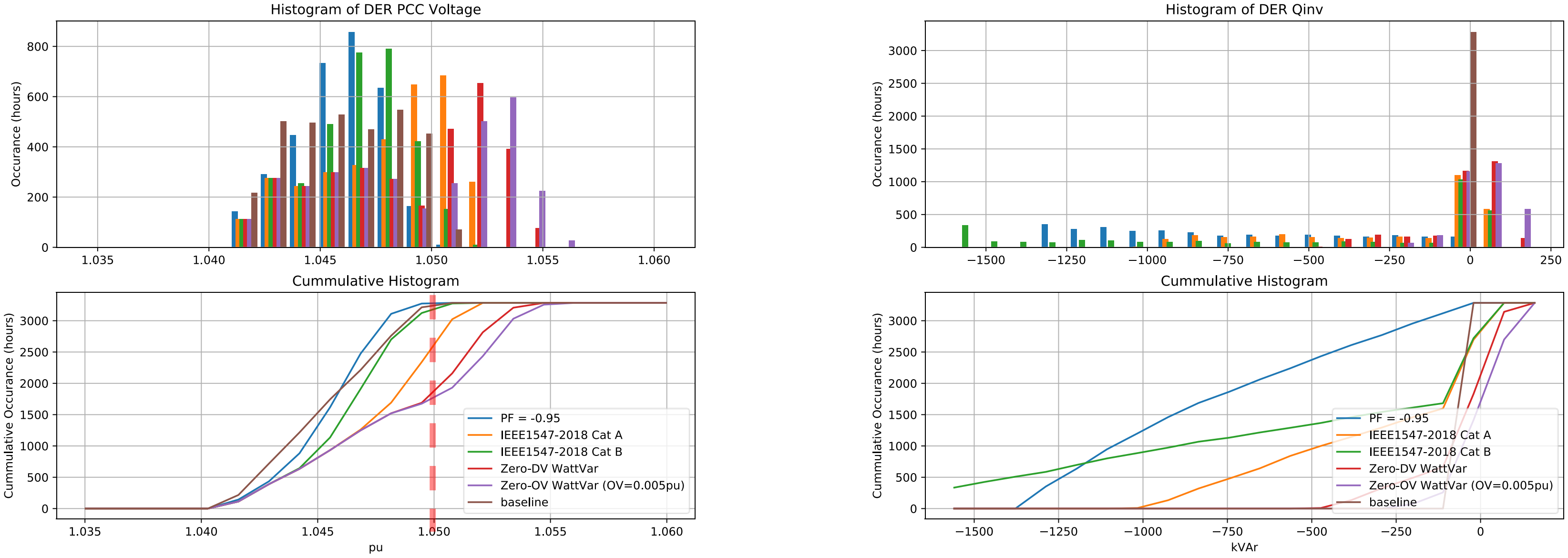
Watt-Var Control Mode



	PF=-0.95	1547 A	1547 B	Zero-DV	Zero-OV
Max V_PCC (pu)	1.050	1.053	1.052	1.055	1.056
DER MWh	8465	8470	8457	8472	8472
DER MVArh	-2775	-1112	-1914	-344	-155
Max Tradeoff MW	0.2	0.1	0.3	0.0	0.0
Tradeoff MWh	7.6	2.3	16.1	0.3	0.2
Feeder Loss MWh	268 +176	268 +178	268 +179	268 +178	268 +178
Feeder Loss MVArh	2517 +1596	2517 +1587	2517 +1615	2517 +1578	2517 +1575

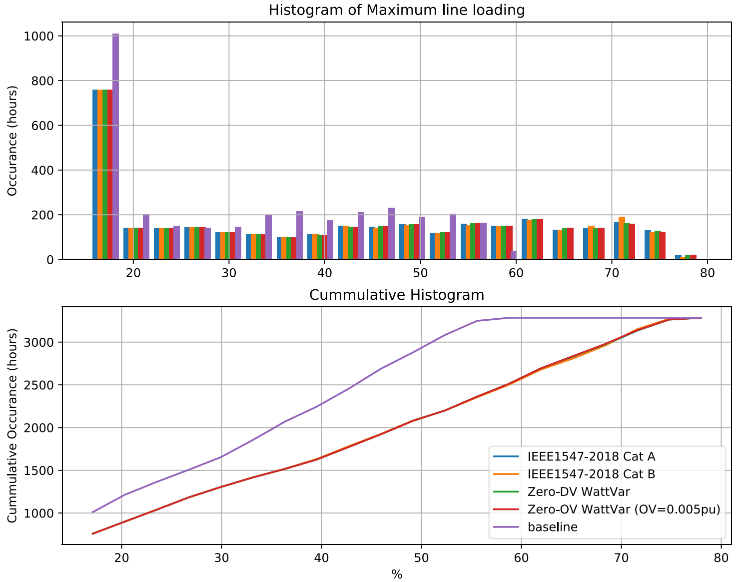
- Watt-var is a non-linear version of constant power factor control
- With same Qmax at full power, watt-var 1547-B results in lower total DER MVArh than that of PF=-0.95 or PF=-0.9

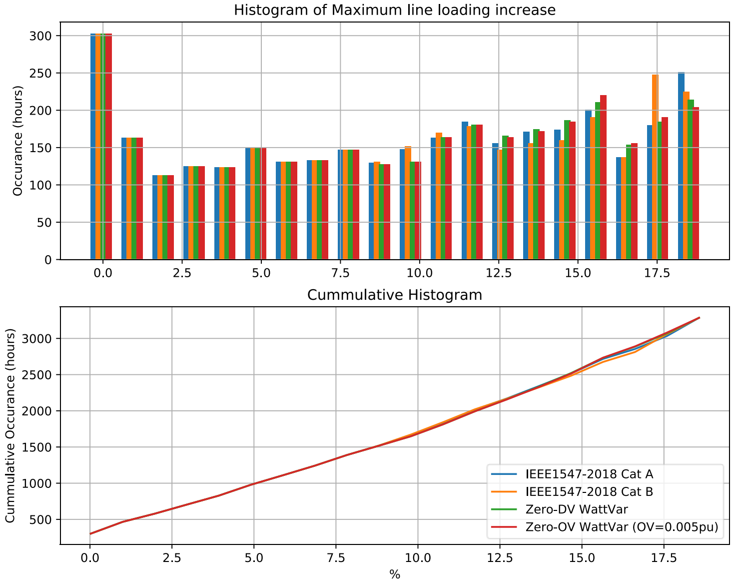
Watt-Var Control Mode (Continue)



- All options present over voltage hours in the simulated year
- Steeper watt-var slope and higher Q value help mitigate over voltage violations (as expected)

Watt-Var Control Mode (Continue)

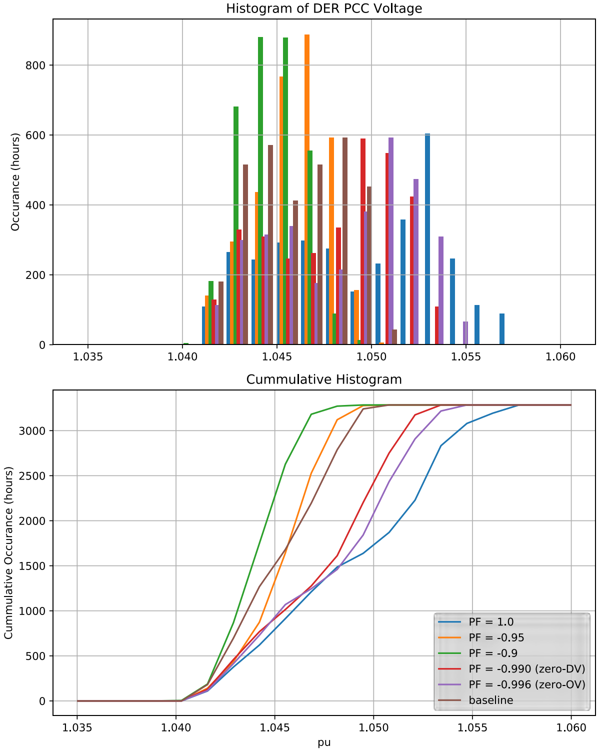




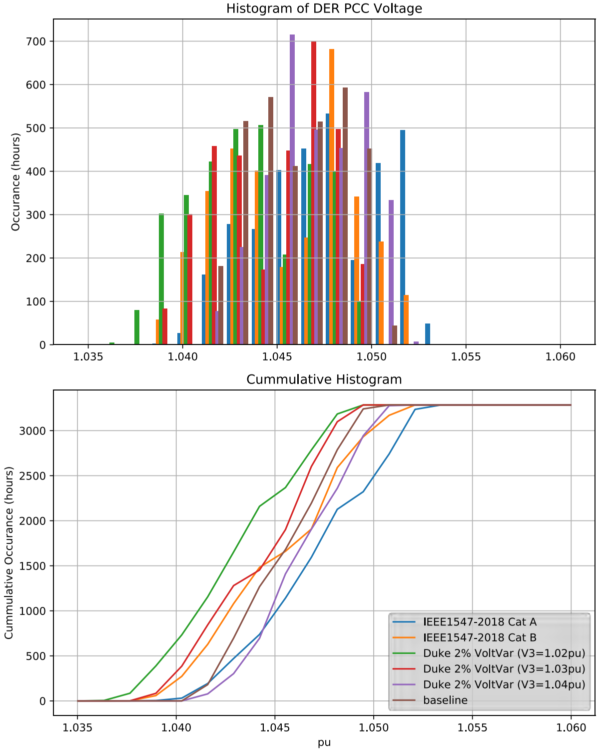
- All options show similar increase (~17%) to the maximum line loading
- No over-loading is observed in this feeder due to the proposed DER

Comparison of Control Options

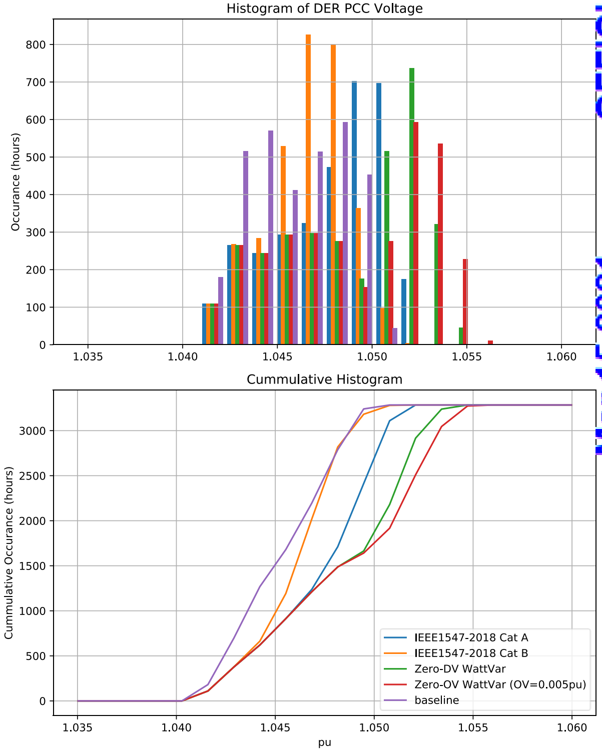
Constant PF



Volt-Var

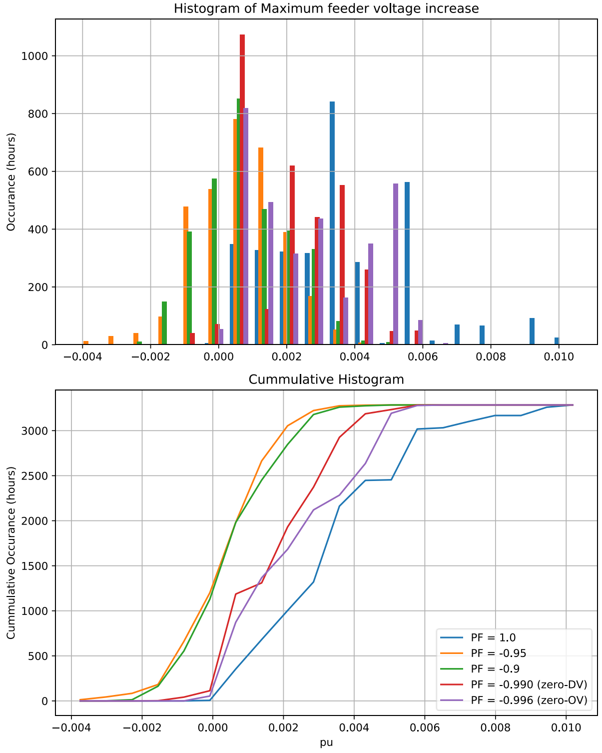


Watt-Var

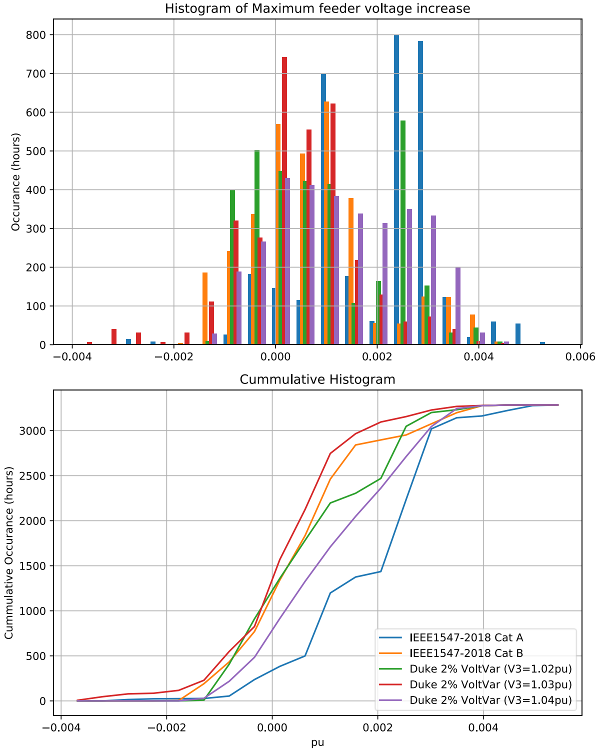


Comparison of Control Options (Continue)

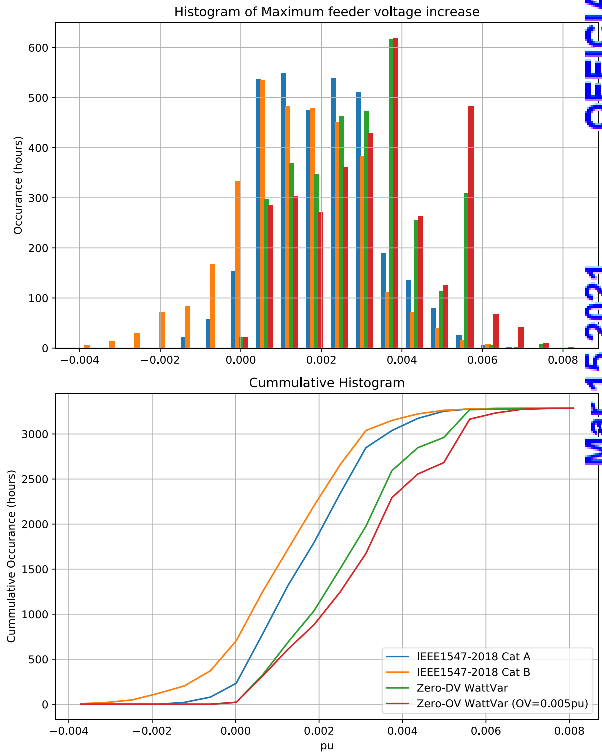
Constant PF



Volt-Var



Watt-Var



- Plots here show the maximum voltage increase on the feeder versus the baseline case

DUKE ENERGY®

BUILDING A **SMARTER** ENERGY FUTURE℠

Update and Discussion: Action Plan to Implement 1547-2018
January 20, 2021

Update and Discussion: Action Plan to Implement 1547-2018 TSRG Meeting

Anthony C Williams, P.E.
Principal Engineer

DER Technical Standards

January 20, 2021

DUKE ENERGY®

Agenda

- Review main revisions
  - Current version is "Duke Energy IEEE 1547 Implementation Guidelines, Rev 3"
    - Rev 2C is the redline version of Rev 3
- Discussion

Priority Groups 1 – 5 Review

Priority	Items
1st	• Reactive power and voltage control • Power quality
2nd	• Voltage tripping and ride through • Frequency tripping and ride through
3rd	• Most important sections of Section 4, General Tech Specs
4th	• Most commonly applied sections of Section 4, General Tech Specs
5th	• Remaining sections of Section 4, General Tech Specs

Priority Table Updates, Group 1

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
1 (DUK-01)	5.2	Reactive power capability of the DER	Category B 35° C ambient or higher at rated voltage	No Reqmt	Eval + Comm Test
1 (DUK-02)	5.3	Voltage and reactive power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-03)	5.4.2	Voltage-active power control	Study in progress	Yes	Eval + Comm Test
1 (DUK-04)	7.4	Limitation of overvoltage contribution	Accept 1547 with additional requirements	No Reqmt	Eval + Comm Test
1 (DUK-05)	7.2.3	Power Quality, Flicker	Accept 1547 in conjunction with continued use of IEEE 1453	No Reqmt	Eval + Comm Test
1 (DUK-06)	7.2.2	Power Quality, Rapid voltage change (RVC)	Continue existing criteria and policy	TBD	TBD, Eval + Comm Test

Priority Table Updates, Group 2

TSRG Priority Order (Duke ID)	IEEE 1547 Section	IEEE 1547-2018 Topic	Technical Position Summary	Interoperability Summary	Test and Verification Summary
2 (DUK-07)	6.4.1	Mandatory voltage tripping requirements (OV/UV)	Have existing setpoints; new 1547 setpoint study in progress	TBD	Eval + Comm Test
2 (DUK-08)	6.5.1	Mandatory frequency tripping requirements (OF/UF)	Have existing setpoints; new 1547 setpoint study in progress	TBD	Eval + Comm Test
2 (DUK-09)	6.4.2	Voltage disturbance ride-through requirements	Study in progress	TBD	Eval + Comm Test
2 (DUK-10)	6.5.2	Frequency disturbance ride-through requirements	Study in progress	TBD	TBD, Eval + Comm Test
2 (DUK-11)	6.5.2.7	Frequency-droop (frequency-power) capability	Evaluation has not begun	No Reqmt	TBD, Eval + Comm Test
2 (DUK-12)	6.5.2.6	Voltage phase angle changes ride-through	Study in progress	No Reqmt	TBD, Eval + Comm Test

Priority Group 1 Revisions

- Significant changes to Section 5.2 – Reactive power capability of the DER
- Divided 7.4 into two sections
  - Added new topic, Section 7.4.1 – Limitation of overvoltage over one fundamental frequency period
- Editorial change to move text from Section 7.4 to the proper section, 7.3

Priority Groups 2, 3, 4 Revisions

- Further clarification and timer settings for Section 4.10 – Enter service

The DER shall not enter service or ramp faster than the times stated below. A randomized time delay is optional and not currently used within the Duke system. As noted in the standard, DER increasing active power steps greater than 20% of Nameplate Active Power rating shall require approval during the system interconnection study process.~~following time delays shall be used~~:

Time Delay	Parameter Label	RDER setting (seconds)	UDER setting (seconds)
Enter Service Delay	ES_DELAY	300	300
Enter Service Ramp Period	ES_RAMP_RATE	300	300
Enter service randomized delay	ES_RANDOMIZED_DELAY	Off	Off

While the active power is ramping during the enter service period, the reactive power shall follow the configured mode and settings.

When connected in parallel with the Area EPS, energy storage DER (ESS) active power rate of change is dependent on the Configuration Active Power Rating per the table below:~~rate of change duration is based on 120 MW/minute, which is 2 MW/second.~~

Rate of Change Duration	Parameter Label		RDER setting (seconds)	UDER setting (seconds)
ESS ≤ 1 MW	None		~~5~~2	n/a
ESS > 1 MW ~~and ≤ 10 MW~~	None		n/a	ESS MW rating / (2 MW/sec)~~5~~
~~ESS > 10 MW~~			~~-~~	~~10~~

Priority Group >5 Updates

- DUK-27 Section 4.7 – Prioritization Of DER Responses
  - Finalized test requirements (use UL certification)
- Updated the Verification and test requirements in several of these sections

Recently Completed Sections

- DUK-05 Section 7.3 – Limitation Of Current Distortion
- DUK-27 Section 4.7 – Prioritization Of DER Responses

Previously Completed Sections

- DUK-13 Section 4.5 – Cease to energize performance requirement
- DUK-28 Section 4.8 – Isolation device
- DUK-23 Section 4.9 – Inadvertent energization of the Area EPS
- DUK-29 Section 4.11.1 – Protection from electromagnetic interference
- DUK-30 Section 4.11.2 – Surge withstand performance
- DUK-22 Section 4.11.3 – Paralleling device
- DUK-26 Section 4.12 – Integration with Area EPS grounding, ready to be implemented
- DUK-01 Section 5.2 – Reactive power capability of the DER
- DUK-05 Section 7.2.3 – Flicker
- ~~DUK-04 Section 7.4 – Limitation of overvoltage contribution~~ (should have been 7.3)

Feedback

- Written feedback and comments will be solicited using comment form
  - Note questions then lets discuss – don't really want all the questions sent in that are mainly just for clarification – this takes a lot of time to address that could be spent on the comments and recommendations
  - It would be helpful to provide both comments and also propose a specific change:

Stakeholder Name	Page Number	Paragraph Number	Comment	Proposed Change
example Question format	3	2	Why is winter data excluded?	None
example Comment format	7	4	Agree with the hours of study.	None
example Comment format	7	4	'the largest' is not clear	Replace 'the largest' with 'the maximum of the three phase currents"
example Recommendation format	10	3	The types of faults is too limited. Include single line to ground faults.	Include SLG faults

  - Suggesting the exact change to the Guidelines reinforces the main point of the comment and provides more information that Duke can specifically address
- Comments will be taken during the meeting and the form will be distributed after the meeting
- Stakeholders may provide written feedback using the feedback form by emailing to: DER-TechnicalStandards@duke-energy.com

DUKE ENERGY®

TSRG: Inverter Volt-VAR Study Update
January 20, 2021

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

TSRG: Inverter Volt-VAR Study Update

Anthony C Williams, DER Technical Standards

January 20, 2021

DUKE ENERGY®

Second Study Overview

- More emphasis on higher voltage feeders so that less DER forces the overvoltage
- Calculate P and Q responses
- Consider a broader variety of controller types
  - Limited controller setting variations: approximately 6 volt-var, 8 pf, 5 watt-var
  - Continued use of volt-watt to backup the primary controller
- Expand the attributes monitored during the study; to inform conclusions
- Quasi-Static Time Series (QSTS) simulation using 8760 hourly load and solar profile
- Compare monitored attributes across the feeders for the various controller types
  - Inform policy development to guide application of DER voltage and reactive power controls, and
  - Develop methods to a) provide a quick assessment of reactive power control effectiveness at a potential UDER interconnection point, and b) indicate the most appropriate type of control
- Final report February, presentation at the following TSRG

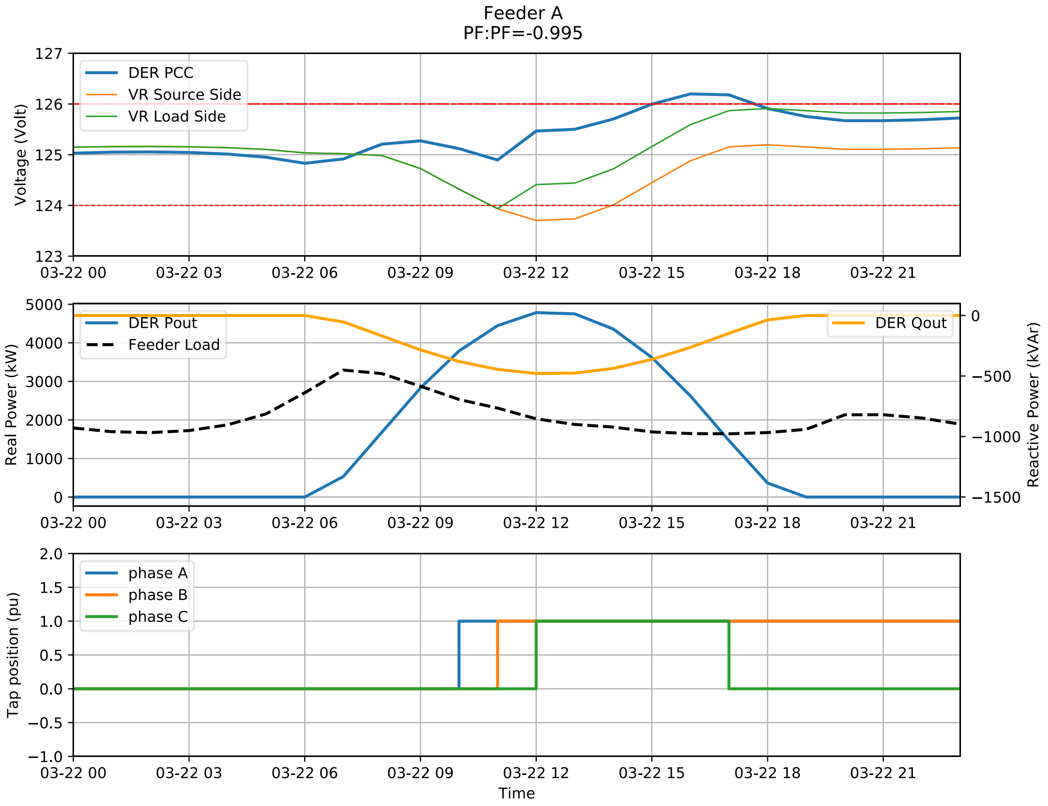
Recent Methodology Improvements

- Yukon capacitor control logic modeled for DEP
  - Provides more reasonable statistics of substation Q demand
- Long term dynamic simulation methods
  - Time dependency (sequencing) of each time step being modeled
  - Next state dependent on last state, not initial state
- Interaction and setting coordination between reactive power controlled DER on the same feeder
- Impact of voltage regulator (upstream to DERs) included in optimal control development

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

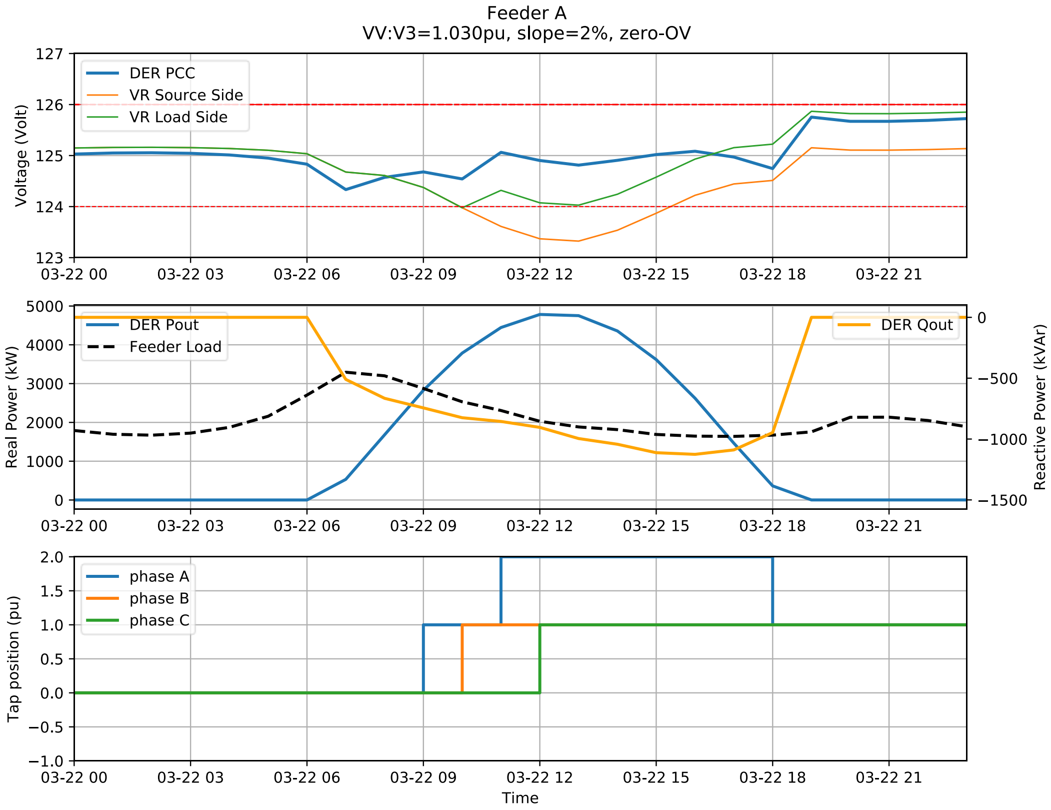
VR + DER Case with Violation

- Station regulator interaction with DER reactive power injection
- DER without VR tap changes resolves the overvoltage
- If conditions cause the voltage at the VR to be near the lower bandwidth
- Reactive injection causes VR to raise taps
- Typically causes violation because voltage limit harder to maintain



VR + DER Case without Violation

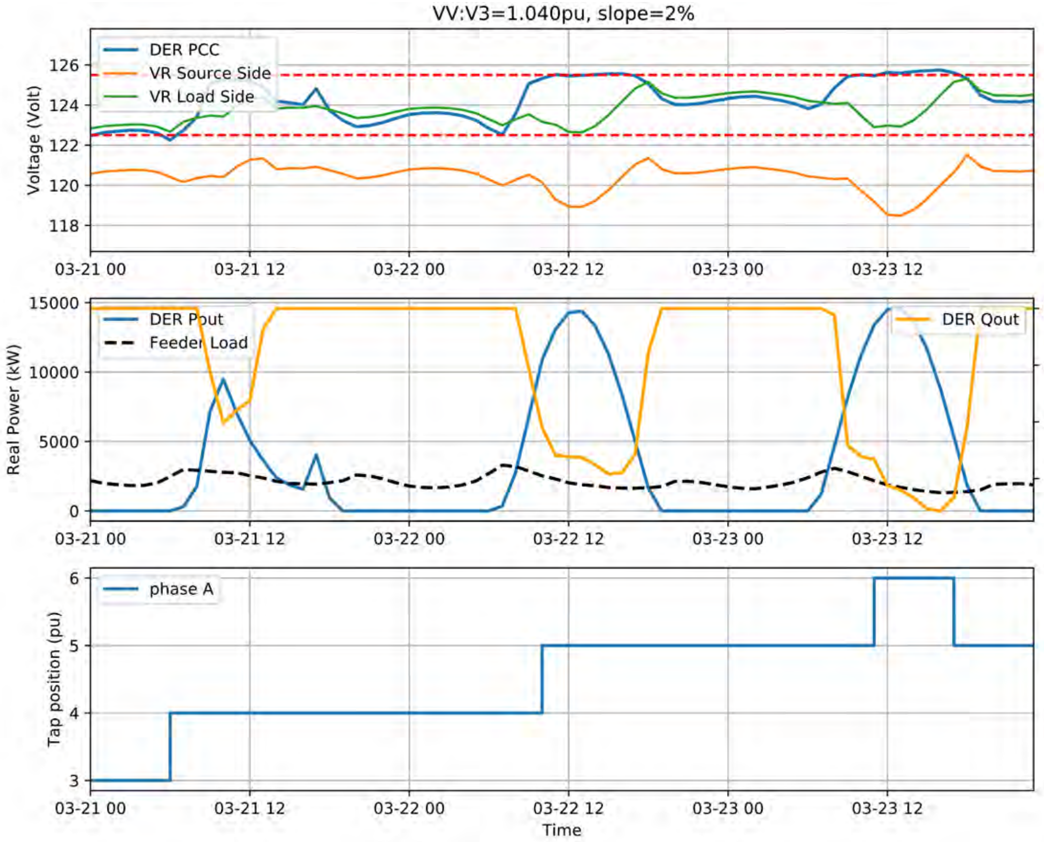
- Same issue, different outcome
- Reactive injection still causes VR to raise taps
- There is enough margin to voltage limit in this case to absorb the rise
- This unacceptable operation is less observable in the field
- The DER and VR are working against each other; creating unnecessary reactive power flow



Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Coordinated VR + DER Case

- Refined Objective:
  Use DER reactive power to maintain voltage below limit with no VR tap increases
- Use a 3-day response to initialize the tap position and evaluate interaction
- Unknown if balanced solutions can be found for each location

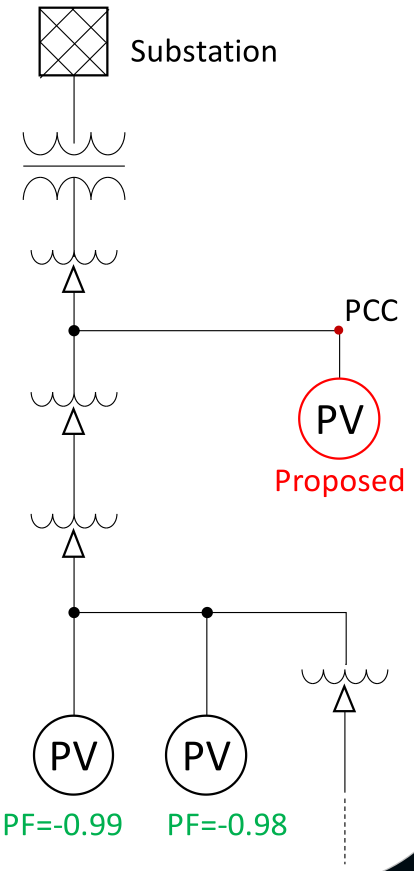


Overview of the Feeder Under Study

Feeder B Characterization Table

Parameter	Value
Feeder peak load	2.51 MW (PF = 0.966)
Connected DERs	Two existing PV (5.5MW each) One proposed PV (5.0MW, 5.25MVA)
Short Circuit Capacity	231 MVA @ Sub (secondary), 153MVA @ PCC
Z_REG (pu @ 1MVA)	0.0002 + j0.0043
Z_PCC (pu @ 1MVA)	0.0008 + j0.0065
Z_PCC2REG (pu @ 1MVA)	0.0006 + j0.0022 (= Z_PCC - Z_REG)
ΔV_Full (pu)	0.0033
∂V / ∂P (puV / MVAr)	0.00066 (= ΔV_Full / Rated_P)
∂V / ∂Q (puV / MVAr)	0.0071
Regulator Control Setting	Vref = 124V, BW = 2V
ΔV_Other_PCC2REG_Max (pu)	0.0139

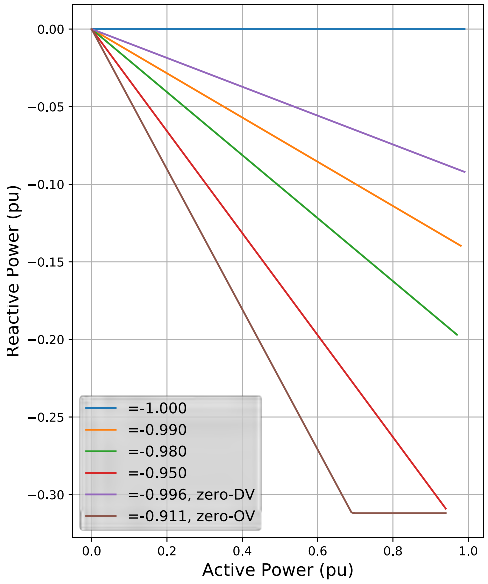
- Values in this table are used to determine the settings for the reactive power controls



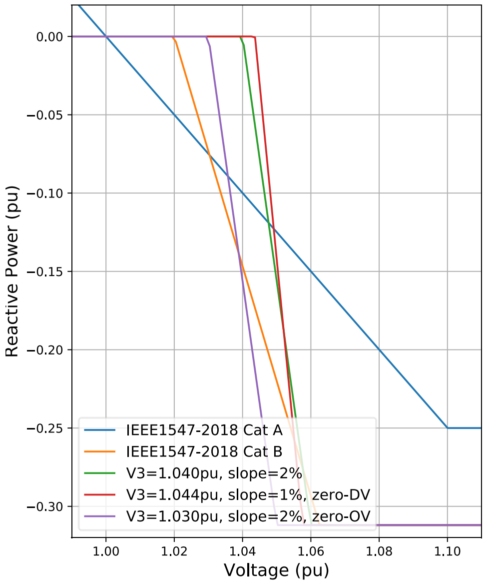
Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Evaluated Control Options

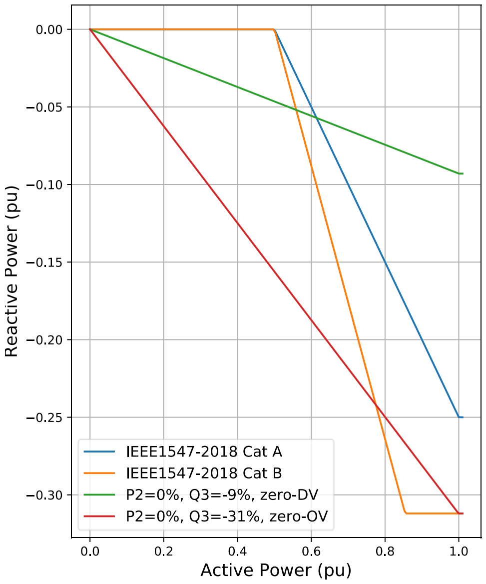
Constant PF



Volt-Var



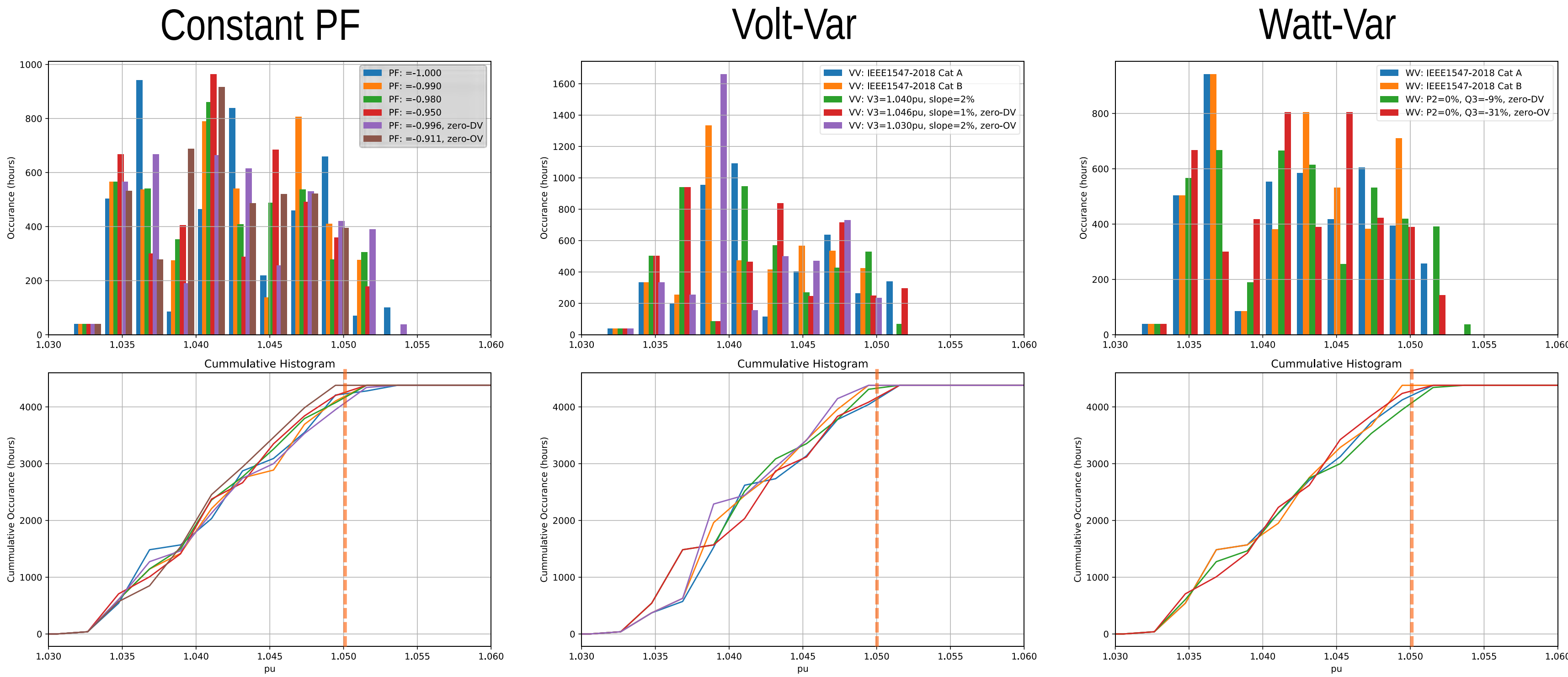
Watt-Var



- zero-OV options are more aggressive than zero-DV options to correct the voltage rise from existing DERs

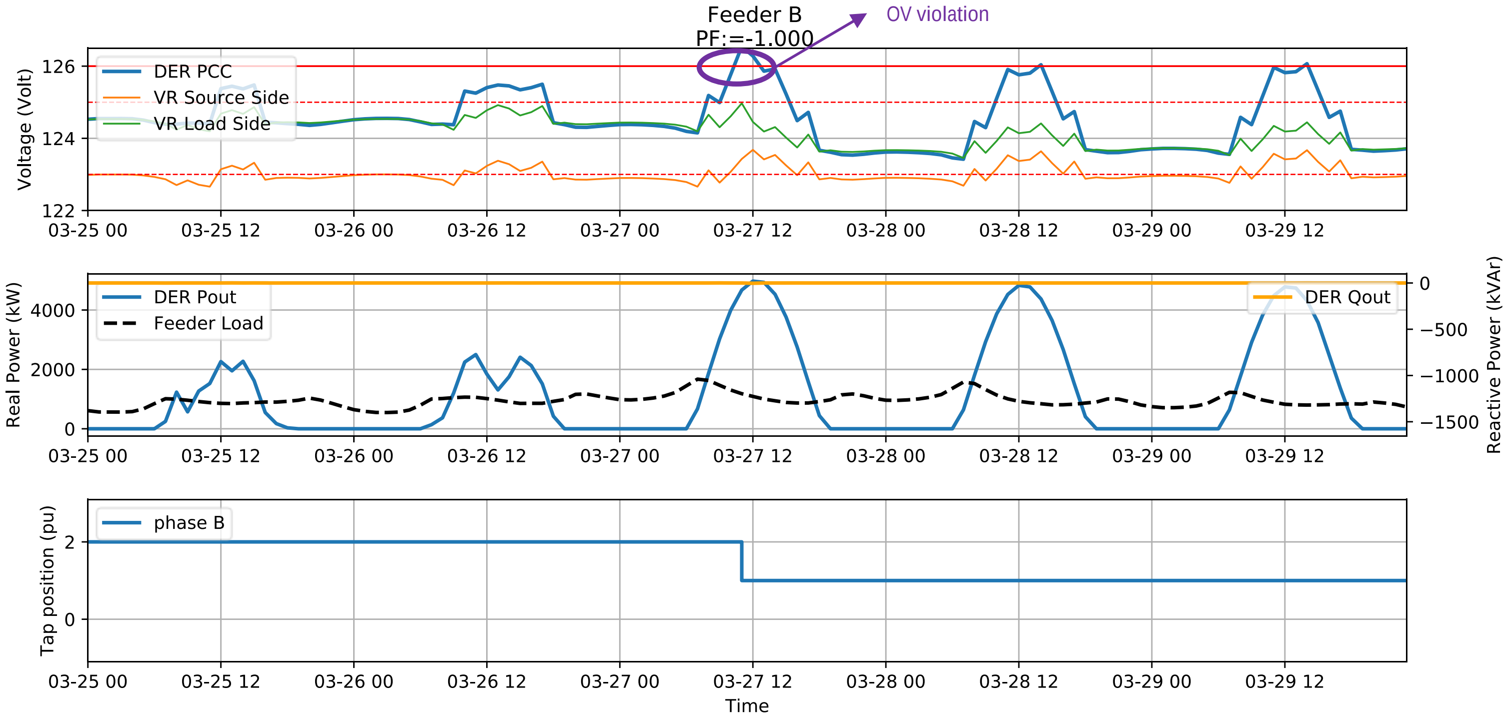
Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Histogram of PCC Voltage in One Year



- All control options are clustered due to proximity of PCC to the voltage regulator
- Zero-OV options work well as they considers the impact of voltage regulator

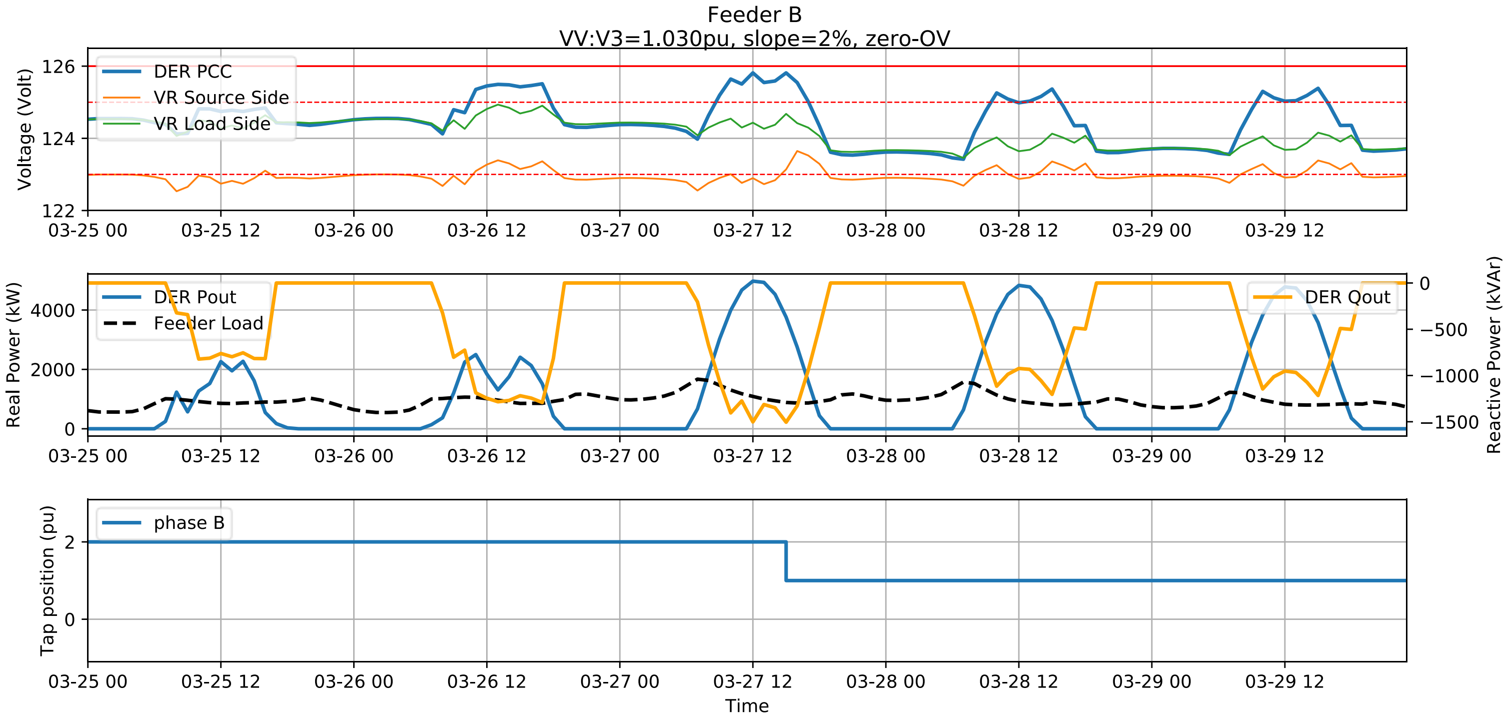
Long Term Dynamic Simulation (Unity PF Mode)



- Five-day (two cloudy and three sunny days) time series simulation
- With unity power factor, DER PCC voltage gets higher than the 105% threshold (i.e., 126V)

Docket No. E-100, Sub 101 and
Docket No. E-100, Sub 101B

Long Term Dynamic Simulation (Volt-Var Mode)



- With the selected Volt-Var control, PCC voltage is always lower than the 105% threshold
- Additional over-voltage margin is required to cover the worst case when VR terminal voltage reaches the top of the BW, 125V, for excursions within the 60 minute time step, and for unanalyzed worse operating conditions

Detailed Summary Tables of All Evaluated Control Options

	PF =-1.000	PF =-0.990	PF =-0.980	PF =-0.950	PF =-0.996, zero-DV	PF =-0.911, zero-OV	VV IEEE1547-2018 Cat A	VV IEEE1547-2018 Cat B	VV V3=1.040pu, slope=2%	VV V3=1.046pu, slope=1%, zero-DV	VV V3=1.030pu, slope=2%, zero-OV	WV IEEE1547-2018 Cat A	WV IEEE1547-2018 Cat B	WV P2=0%, Q3=-9%, zero-DV	WV P2=0%, Q3=-31%, zero-OV
Max V_PCC (pu)	1.055	1.052	1.053	1.051	1.054	1.051	1.052	1.051	1.051	1.052	1.051	1.053	1.05	1.054	1.051
hours_(Vpcc>1.05)	264	363	356	253	507	103	379	148	208	446	0	591	45	507	179
min_Vpcc	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033
hours_(Vpcc<0.95)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hours_(Volt-Watt ON)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
max_Vinv	1.06	1.05	1.049	1.043	1.054	1.04	1.05	1.044	1.047	1.051	1.039	1.05	1.048	1.054	1.043
hours_(Vinv>1.05)	1295	86	0	0	532	0	0	0	0	304	0	116	0	532	0
min_Vinv	1.033	1.033	1.033	1.032	1.033	1.03	1.032	1.03	1.033	1.033	1.031	1.033	1.029	1.033	1.033
hours_(Vinv<0.95)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
max_Vfdr	1.061	1.062	1.062	1.062	1.061	1.061	1.062	1.061	1.062	1.061	1.061	1.062	1.061	1.061	1.062
hours_(Vfdr>1.05)	2514	2645	2759	2869	2547	2861	3122	3503	2614	2514	3510	2514	2514	2547	2802
min_Vfdr	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033
hours_(Vfdr<0.95)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
max_sub_kW	2513	2513	2513	2513	2513	2513	2513	2513	2513	2513	2513	2513	2513	2513	2513
min_sub_kW	-14847	-14831	-14795	-14698	-14847	-14698	-14837	-14793	-14826	-14841	-14687	-14755	-14605	-14847	-14687
max_sub_MVAr	1	1	2	2	1	2	1	2	1	1	2	2	2	1	2
min_sub_MVAr	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
max_sub_Amps	357	358	357	356	358	356	358	357	358	358	356	357	355	358	356
max_fdr_loading (%)	57	57	57	56	57	56	57	57	57	57	56	57	56	57	56
hours_(fdr_loading>100%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DER MWh	9114	9112	9108	9096	9114	9096	9113	9109	9112	9114	9096	9103	9084	9114	9094
DER MVArh	1	-1298	-1849	-2979	-846	-3744	-2068	-3200	-1045	-435	-3822	-1096	-1889	-847	-2844
total_INV_MWh	9138	9137	9133	9122	9138	9123	9138	9135	9137	9138	9124	9128	9110	9138	9121
total_INV_MVArh	304	-989	-1534	-2645	-542	-3394	-1753	-2869	-736	-131	-3477	-786	-1562	-542	-2513
Max Increased_INV_Loss kW *	0	1	1	3	0	4	1	2	1	1	4	2	5	0	3
Increased_INV_Loss MWh	0	1	2	5	0	8	2	5	1	0	7	1	4	0	4
Max Tradeoff kW	6	20	55	157	4	157	14	67	25	11	167	97	250	4	167
Tradeoff MWh	1	2	7	19	1	19	2	6	2	1	18	12	30	1	20
max_fdr_loss_kW	457	458	459	454	457	454	458	459	458	457	454	457	454	457	454
Feeder Loss MWh	502	506	508	512	504	515	511	517	505	502	519	504	506	504	512
max_fdr_loss_kVAr	2869	2877	2881	2861	2871	2861	2875	2882	2878	2874	2861	2878	2859	2871	2861
Feeder Loss MVArh	3161	3173	3181	3208	3166	3230	3186	3210	3173	3163	3226	3171	3193	3166	3204

* Assuming 1% conduction loss for DER inverter

- This table is used to compare and select the optimal control options

Simplified Table to Focus on those Optimal Options

	PF =-1.000	PF =-0.996, zero-DV	PF =-0.911, zero-OV	VV V3=1.040pu, slope=2%	VV V3=1.046pu, slope=1%, zero-DV	VV V3=1.030pu, slope=2%, zero-OV	WV P2=0%, Q3=-9%, zero-DV	WV P2=0%, Q3=-31%, zero-OV
Max V_PCC (pu)	1.055	1.054	1.051	1.051	1.052	1.051 ↓	1.054	1.051
hours_(Vpcc>1.05)	264	507	103	208	446	0 ↓	507	179
DER MWh	9114	9114	9096	9112	9114	9096 ↓	9114	9094
DER MVArh	1	-846	-3744	-1045	-435	-3822 ↑	-847	-2844
Max Increased_INV_Loss kW	0	0	4	1	1	4 ↑	0	3
Increased_INV_Loss MWh	0	0	8	1	0	7 ↑	0	4
Max Tradeoff kW	6	4	157	25	11	167 ↑	4	167
Tradeoff MWh	1	1	19	2	1	18 ↑	1	20
Feeder Loss MWh	502	504	515	505	502	519 ↑	504	512
Feeder Loss MVArh	3161	3166	3230	3173	3163	3226 ↑	3166	3204

- Although different control options result in different levels of DER reactive power absorption (i.e., “DER MVArh”), the impact to DER energy yield (i.e., “Tradeoff MWh”) and feeder losses (i.e., “Feeder Loss MWh” and “Feeder Loss MVArh”) is limited

DUKE ENERGY®

*BUILDING A **SMARTER** ENERGY FUTURE*SM

Metrics

- Site specific (fixed)
  - Rated Pgen, Qgen at PCC and inverter
  - SCC at Station, PCC
  - X, from PCC back to source
  - R, from PCC back to source
  - PCC Voltage, Basecase (P=Q=0)
  - PCC Voltage, Initial (P=Prated, Q=0)
  - Min load kva/Peak load kva
  - Feeder head power flow, kW and kVAR
  - ΔV/ΔP (Presp, derivative of voltage variation to real power injection)
  - ΔV/ΔQ (Qresp, derivative of voltage variation to reactive power injection)
  - Qresp/Presp = (dV/dQ) / (dV/dP)
  - ΔV/ΔPrated (total voltage change at rated active power)
  - ΔV/ΔQrated (total voltage change at rated reactive power)
- Controller specific
  - Overvoltage Magnitude, PCC, Feeder, Inverter (V)
  - Overvoltage Occurrences, PCC, Feeder, Inverter
  - Feeder Active Power Max, Min (kW)
  - Feeder Reactive Power, Max, Min (kVAR)
  - Total MWh, MVARh, at PCC, Inverter
  - Tradeoff MW, MWh