aarv_test

June 11, 2024

1 Autonomously Adjusting Reference Voltage Tests

The purpose of autonomously adjusting reference voltage (AARV) is to mitigate rapid voltage change (RVC), without affecting the utility's control of steady-state voltage or the DER's steady-state reactive power. AARV may be used with a volt-watt function that mitigates steady-state overvoltage, but otherwise AARV does not regulate steady-state voltage.

1.1 Historical Background

AARV was identified in the course of an applied research project on optimal smart inverter settings, which proved sensitive to location and size of the DER (2015 paper). AARV seemed to offer a uniform default setting approach that could be easier to apply for DER, and it was included in IEEE 1547-2018, but not specified as a default.

The AARV function was implemented in the *ExpControl* component in *OpenDSS*, using system parameters like gain, deadband, and reactive power bias instead of the V1..V4 and Q1..Q4 points (2019 paper). A companion notebook on this site shows how the system parameters are translated to the table parameters required in IEEE 1547-2018. In the mitigation of RVC, several examples have shown that AARV outperforms a static volt-var characteristic, with less reactive power needed from the DER (2019, 2023 papers).

References:

- 2015 Conference Paper: https://doi.org/10.1109/PESGM.2015.7286560
- 2019 Conference Paper: https://doi.org/10.1109/PVSC40753.2019.8981277
- 2023 Conference Paper: https://doi.org/10.1109/PESGM52003.2023.10252317

1.2 Code Samples

There are Python code cells in this notebook that create plots and text outputs to illustrate various points of application, implementation, and testing. A live version of this notebook is available at gridhub, under an open-source license and copyright that permit reuse and modification. Run the following Python code cell to define support functions using Numpy and Matplotlib.

1.3 AARV Test from 1547.1-2020

Clause 5.14.5 of IEEE 1547.1-2020 describes a specific test for AARV. In all other tests, AARV is to be disabled. Four AARV tests are described, at the time constant values $Tref = 300$s and 5000s, each of those with source voltage steps to (V1+V2)/2 and (V3+V4)/2. Before each voltage step, the steady-state reactive power, Q, should be zero at V=Vref. The volt-var characteristic V1..V4 and Q1..Q4 points are set to the default values.

The voltage steps result in step changes of Q to 0.5*Q1 and 0.5*Q4, respectively, with some delay from the open-loop response. These new Q values should follow an exponential decay back to zero, governed by *Tref* = 300s or 5000s. The test criteria specifies that after one time constant, *Tref*, the value of Q should be less than 10% of Q1 or Q4, respectively. However, this behavior depends on whether the volt-var characteristic includes a deadband.

Tref is defined as the time constant for AARV reference voltage. On the other hand, *Tresponse* is defined as an open-loop response time, which is converted to an exponential time constant in the Python code below. Furthermore, the simulation is run at a constant time step, *dt*, so both time constants may be implemented as constant decrement factors. If the real hardware controller operates at a constant sample interval, it may also use constant decrement factors to save the time of repeatedly evaluating the exponential functions.

Passing this test verifies implementation of *Tref*, but not the impact of AARV on a system with grid impedance.

1.3.1 Simulation of AARV Tests

Run the following Python code cell to define a function that simulates and plots an AARV test. The input parameters are:

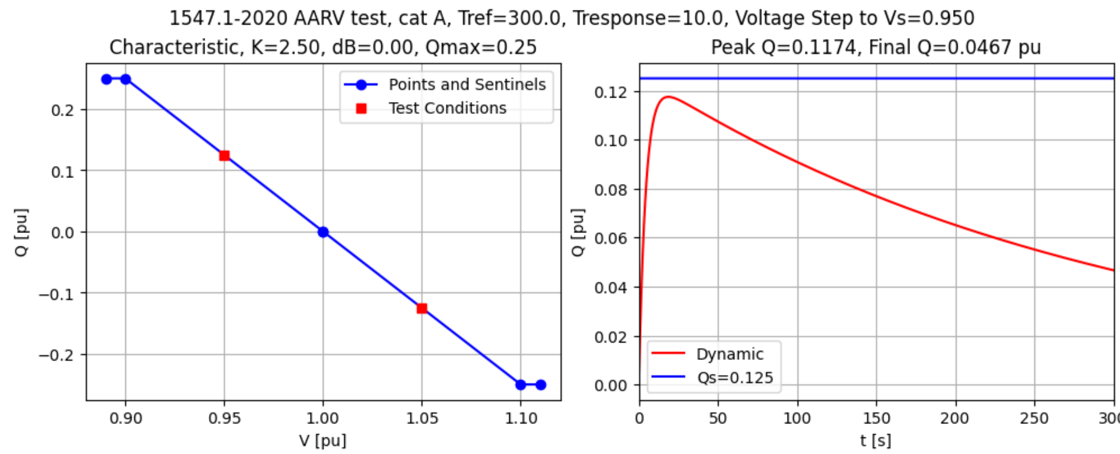
- *tag* is a text label to appear in the plot.
- *Vref*, *dB*, *K*, *Qmax*, and *Qmin* are the system parameters to define the volt-var characteristic
- *Tref* is the AARV time constant, which ranges from 300s to 5000s. No default value was provided in IEEE 1547, but 300s works well whenever AARV is enabled.
- *Tresponse* is the open-loop response time, which ranges from 1s to 90s. The default in IEEE 1547 is 10s for category A and 5s for category B.
- *dt* is the time step for simulation and plotting.
- *bShiftTable* is a flag to choose between two different implementations of AARV:
  - *True* means that the V1..V4 points in the volt-var characteristic are shifted each time *VRef* changes. This procedure strictly follows language in the footnote in IEEE 1547-2018, and it performs as intended in simulation. However, it's not efficient and it may lose track of the original settings for V1..V4.
  - *False* means that instead of modifying V1..V4, the voltage used for interpolation is adjusted with an offset to the **original** value of *Vref*, denoted as *Vset* in the code. This method also performs as intended, without regenerating the interpolation table at each time step, and without losing track of the original settings for V1..V4. In the Python function signature, the default value is *False* to indicate that this might be the preferred implementation. (It is also close to the way *OpenDSS* implements AARV).

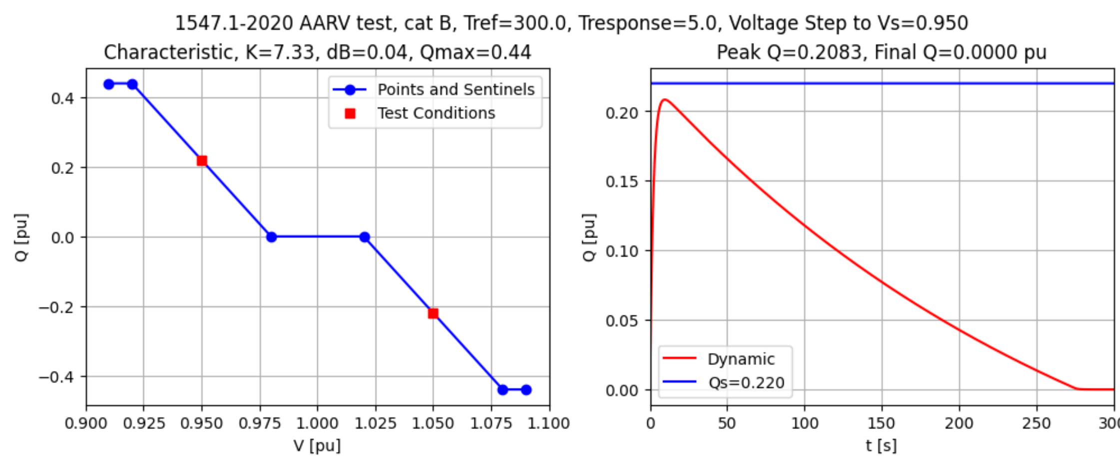
The function runs for one time constant, *Tref*, and it provides numerical outputs of the peak and final Q. The test procedure ensures that limits on *Vref* will be met, so the function does not check the limits during execution.

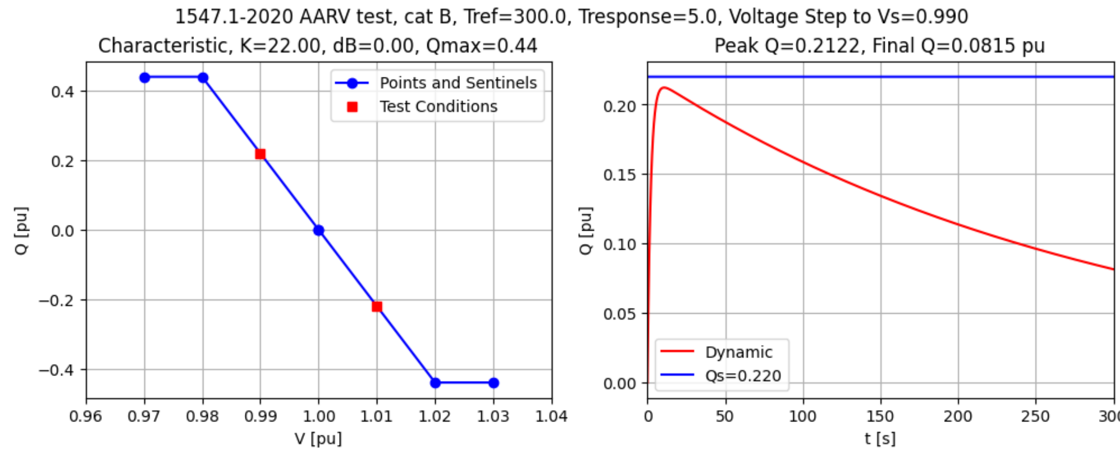
1.3.2 Examples of AARV Tests

Run the following Python code cell to simulate three example AARV tests. In each test, the voltage steps to (V1+V2)/2. The volt-var characteristic is plotted to the left, and the dynamic response of Q is plotted to the right.

- For default Category A, there is no deadband. The steady-state value of Qs would be 0.125 pu, but Q only reaches 0.1174 pu due to the open-loop response time constant. The value of Q at $Tref$ is 0.0467 pu, which is 18.68% of Q1, so this result does not pass the test.
- For default Category B, there is a deadband. The steady-state value of Qs would be 0.22 pu, but Q only reaches 0.2083 pu due to the open-loop response time constant. The value of Q at $Tref$ is 0.0, because the voltage has entered the deadband by that time, so this result passes the test.
- For Catagory B with no deadband and maximum slope (or gain), Q reaches 0.2122, considering the open-loop response time constant along with the higher gain. The final value of Q at $Tref$ is 0.0815 pu, which is 18.52%, so this result does not pass the test.







1.3.3 Conclusion

- The test in clause 5.14.5 of IEEE 1547.1-2020 was only passed for the default Category B characteristic. Q decreases to 0 at *t=Tref* because V is within the deadband by that time, and 0 is less than 10% of Q1. However, with a deadband, the test fails because Q decreases to about 19% of Q1 at *t=Tref*. This occurs for the default Category A characteristic, and for a higher-gain Category B characteristic with no deadband. The test specification in clause 5.14.5 should be reviewed, and corrected if necessary.
- AARV is most advantageous without a deadband, so the *Tref* test procedure should include that use case. All three numbered volt-var characteristics in IEEE 1547.1-2020, in Tables 26-28, include a deadband. There should also be a *Tref* test characteristic for Category B without a deadband.
- In discussions of P1547 Subgroup 2, some members claim that AARV was never intended for Category A DER, only for Category B. However, IEEE 1547-2018 and 1547.1-2020 don't state such an exemption, and clause 5.14.5 of IEEE 1547.1-2020 describes a *Tref* test for Category A. If 1547.1-2020 is amended, there is an opportunity to clarify whether or not Category A DER shall be tested for *Tref*.

1.4 BSD 3-Clause License