Impact of Photovoltaic Generation and Natural Gas-Fired Generation on Large-scale Power Systems

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Background and Motivation

- With the increasing penetration of inverter-based resources (IBRs), grid characteristics of large-scale power systems, including steady-state and dynamic performance, could experience changes.
- There is an increasing trend of natural-gas based generation in PJM territory.
- Previous studies have mainly focused on the impacts of IBRs on distribution systems. Discussion of the impact on transmission level has been limited.
- Existing studies did not utilize actual large-scale interconnected models and the locations of the added did not necessarily reflect future trends.
- This study creates future PV scenarios by integrating PV projects from the PJM generator interconnection queue reviewed by the end of 2020.

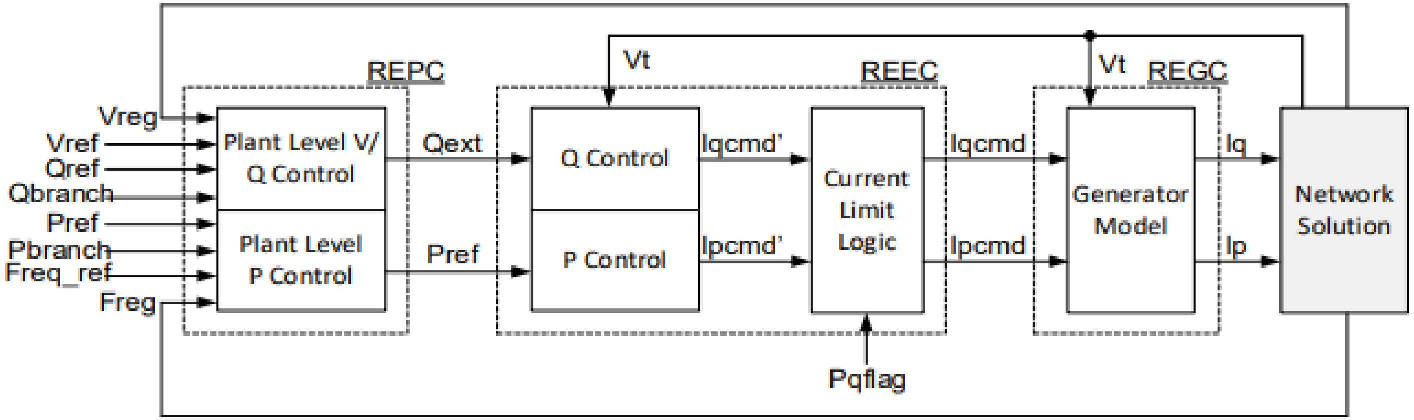
Study Cases

- The study cases used in this work is summarized as follows,
  - **Base Case**: 2024 MMWG spring light load model
  - **Gas Scenario**: 1GW new gas generation in Dominion Energy Virginia (DEV) area. Information of the newly proposed gas plant is provided by DEV.
  - **PV Scenario**: 1GW additional solar generation in DEV area. New solar projects are selected from the PJM interconnection queue. Under construction projects have the priority to be added first.

Modeling of PV generation

- Power flow model
  - The reactive power capability are modeled as recommended in FERC Order 827. New non-synchronous generators are required to provide dynamic reactive power within the power factor of 0,95 leading to 0.95 lagging.

- Dynamic model
  - Generic model with default parameters
  - Electrical controller module
  - Generator converter module



Steady state analysis

- Short circuit analysis

  - Grid strength could be quantified as the sensitivity of the terminal voltage to its current injection changes, which is related to the short circuit MVA (SCMVA) level.
  - Weak grids could pose challenge to the stable operation of IBRs.
  - IBR provide much less short circuit current (SCMVA) compared to conventional generators.

- Voltage profile

  - Bus voltage magnitudes should be maintained within operating limits
  - Integration of IBRs and natural-gas generation could result in variations in regional voltage profiles

- Voltage stability

  - Lack of reactive power capability is the most common cause of voltage instability.
  - Integration of new generating resource could have an impact on the available reactive power capability.

Dynamic study

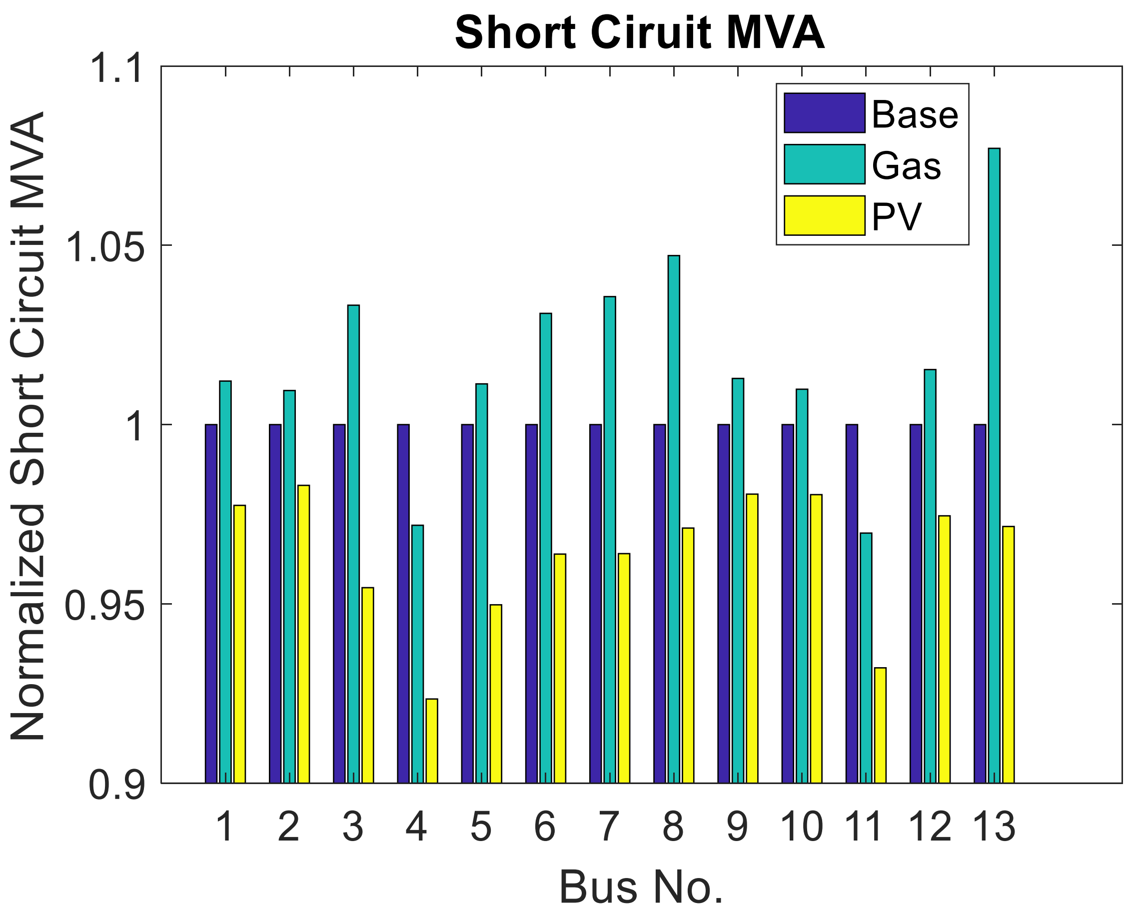
- Dynamic voltage response
  - Differences in control characteristics between PV inverters and conventional synchronous generators could affect system dynamic voltage responses.
- Transient stability
  - Conventional generators contribute to system inertia and can provide sufficient synchronizing capability during disturbances that cause an imbalance between mechanical power and electrical power.
  - PV plant does not have inertia, which could seriously weaken synchronizing capability during disturbances and lead to stability issues

Case Study – Short Circuit Analysis

- Short circuit analysis implemented in PSS/E, in compliance with the IEC 60909 standard.

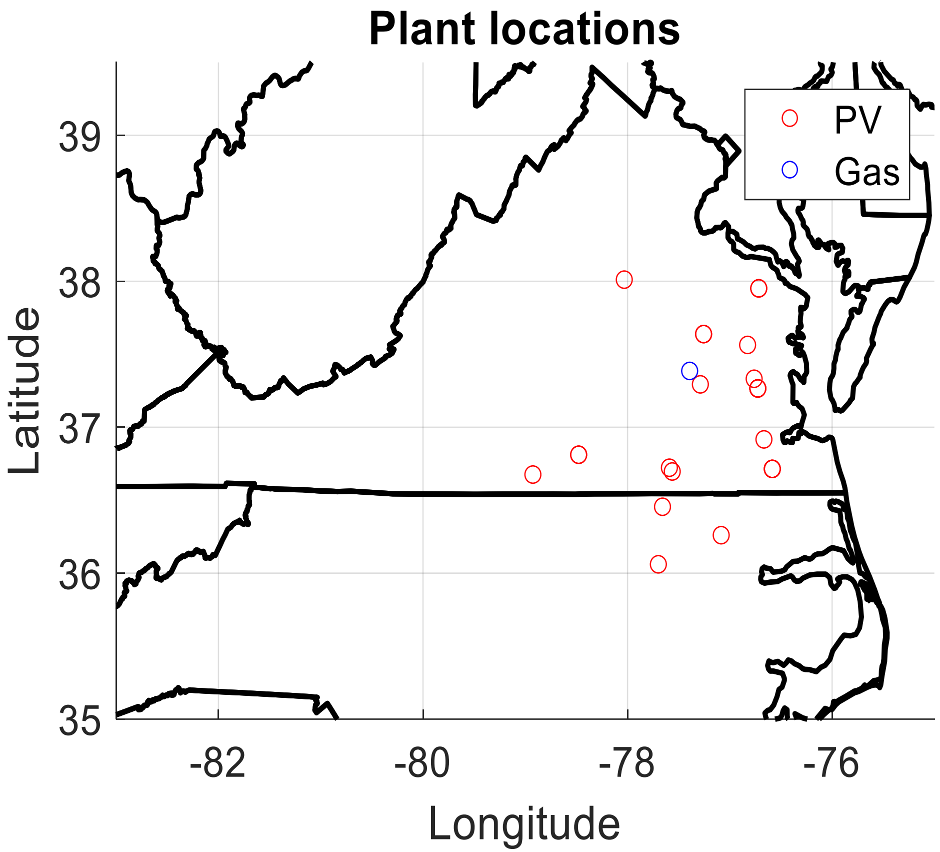
- SCMVA values are calculated at important load buses in Central Virginia area and normalized with respect to the base scenario.

- New gas plant result in a higher SCMVA, while PV plants reduce short circuit level.



Case Study – Voltage profile

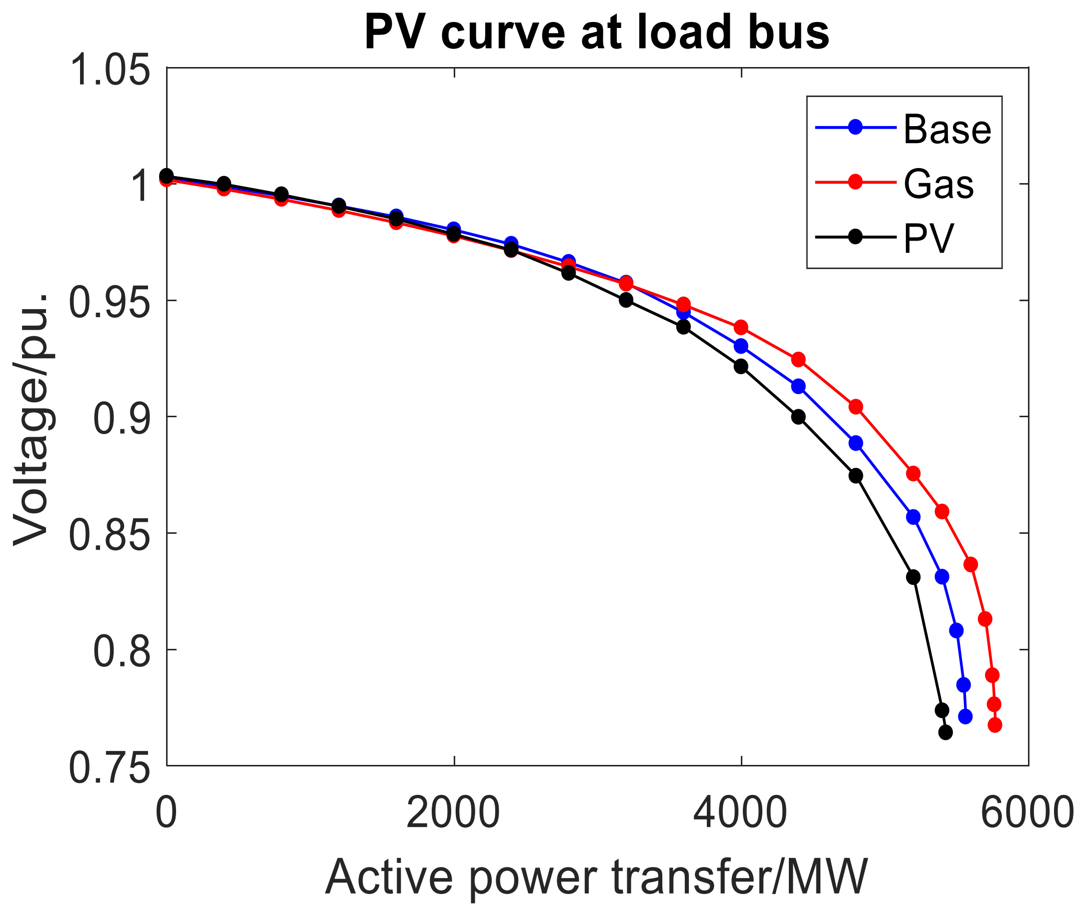
- Single line outages within DEV area are investigated.
- Similar voltage violations are observed.
- The new gas plant in the gas scenario introduces several flow violations in the local area.
- PV scenario is less likely to create flow violations due to the more dispersed locations.



Case	Low voltage violations			High voltage violations			Flow violations
	115kV	230kV	500kV	115kV	230kV	500kV	
Base	4	11	0	35	9	2	3
Gas scenario	4	11	0	34	9	2	6
PV scenario	4	11	0	30	10	2	2

Case Study – Voltage Stability

- A higher loading scenario of the Central Virginia area are investigated.
- Loads inside the Central Virginia area are scale up and generators in the rest of the DEV area are scaled up to accommodate the load increase.
- PV curve at an important load bus in the Central Virginia area is shown.
- The integration of the new gas plant increase the voltage stability margin by 200MW, while equal amount of solar generation decrease the margin by 140 MW.

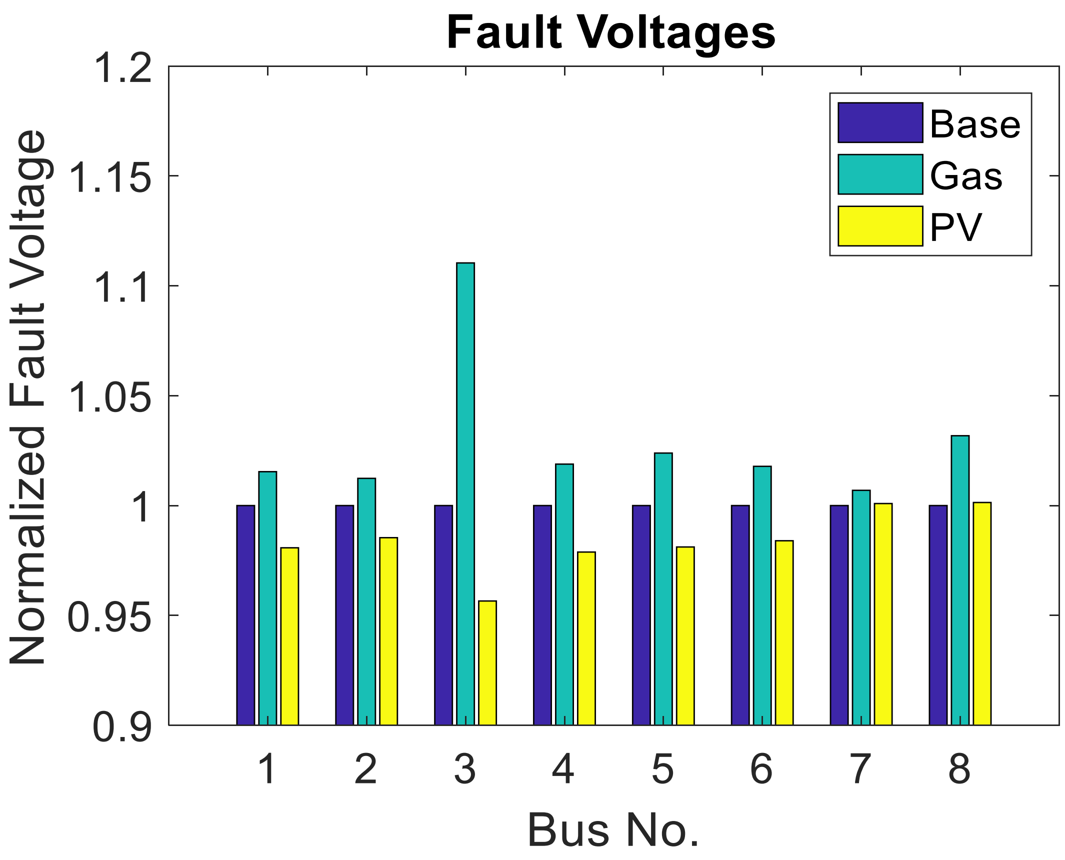


Case Study – Fault voltages

- In addition to the steady state voltage profiles, local voltages during bus faults are compared under different scenarios

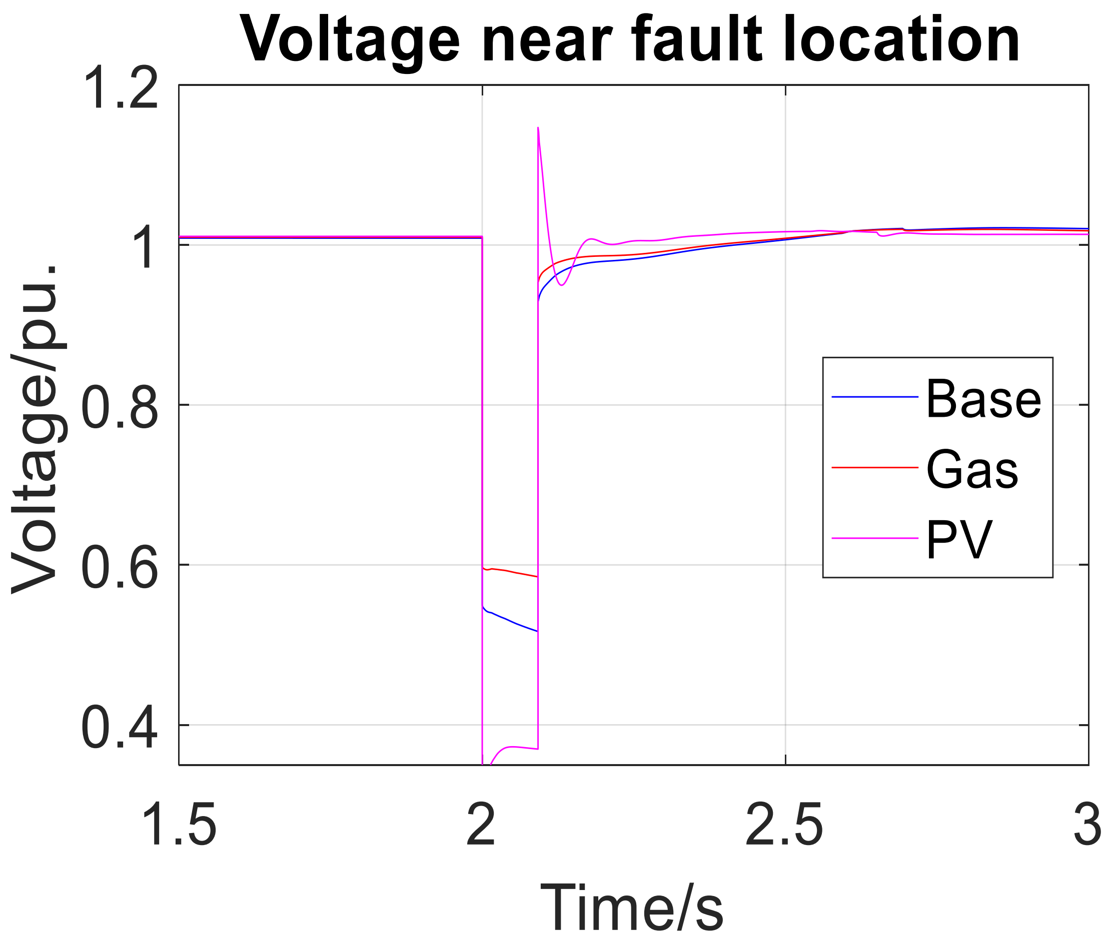
- Bus locations that are one level away from the fault location are plotted.

- The new gas plant in the Central Virginia area provides additional reactive power support during fault conditions.

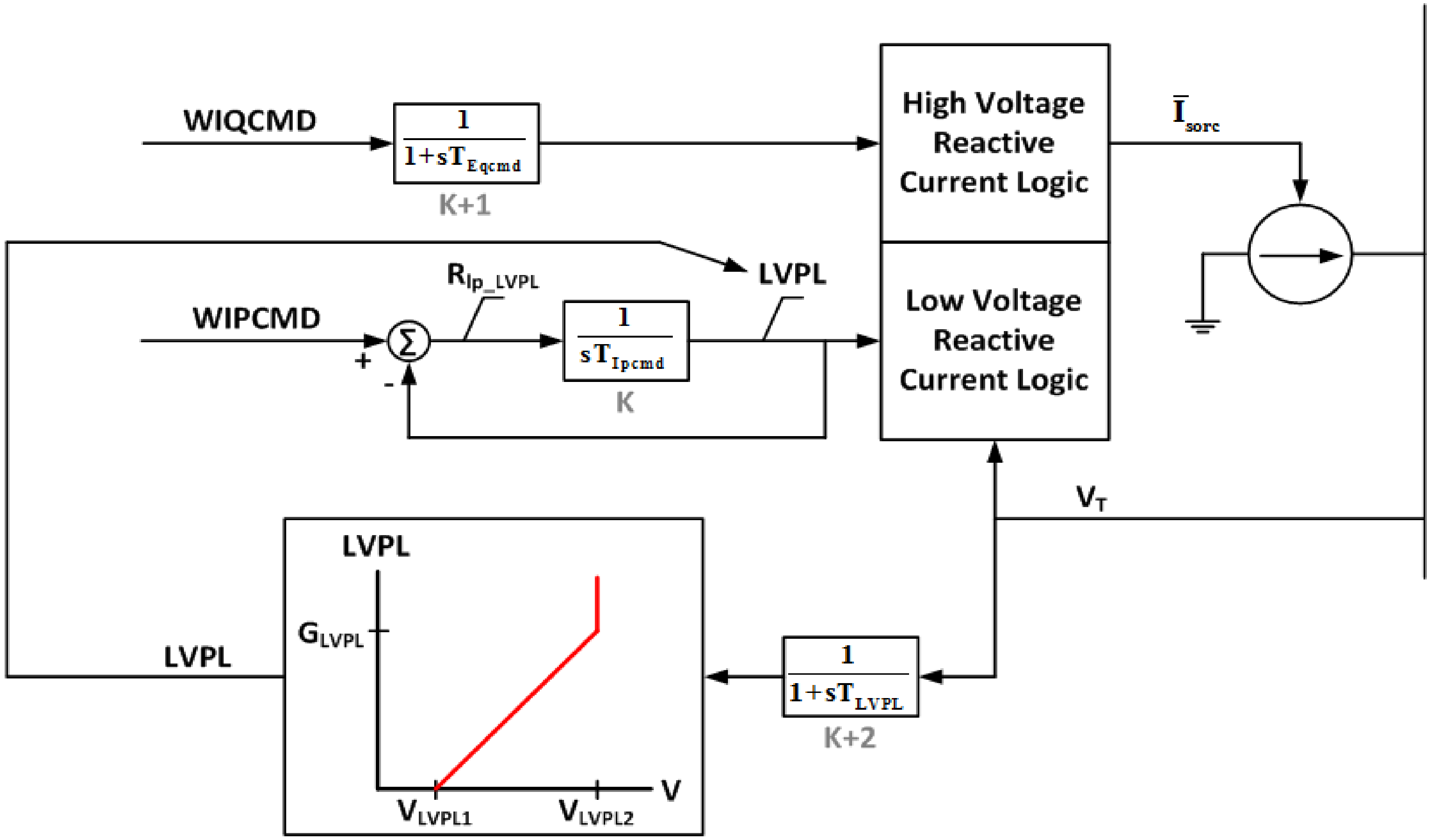


Case Study – Dynamic response

- Dynamic voltage responses after a three-phase branch fault in the Central Virginia area are simulated.
- Additional gas generation could provide more reactive power support.
- Dynamic reactive power capability of the PV plant is limited by the terminal voltage and current rating.
- A transient overvoltage after clearing is observed in the PV scenario.



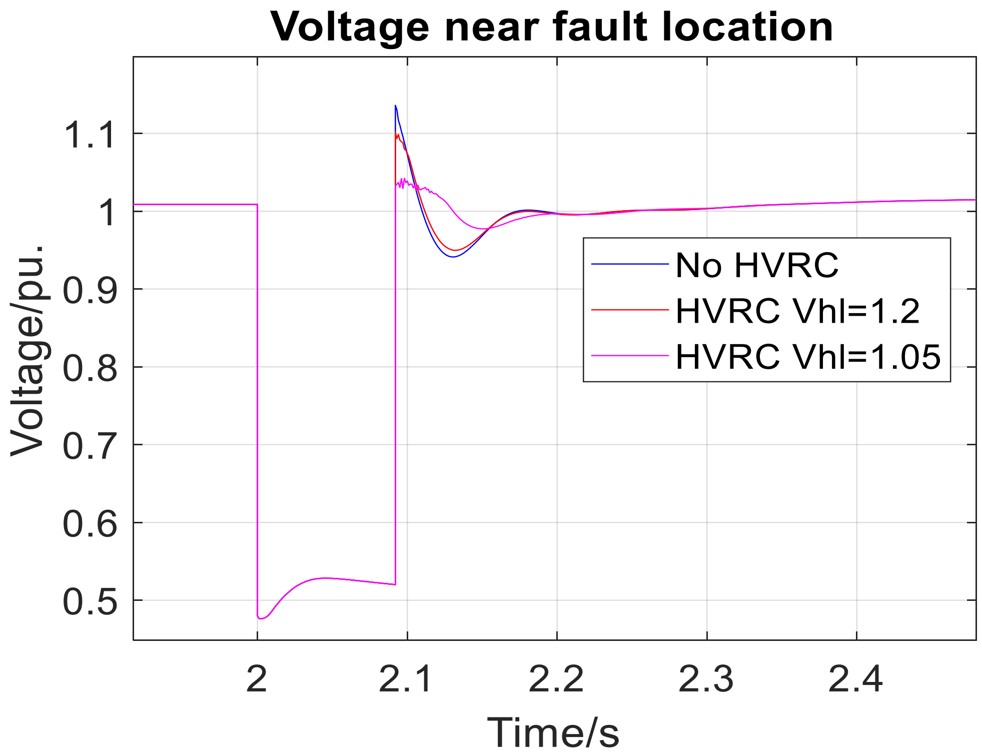
Case study – Dynamic response

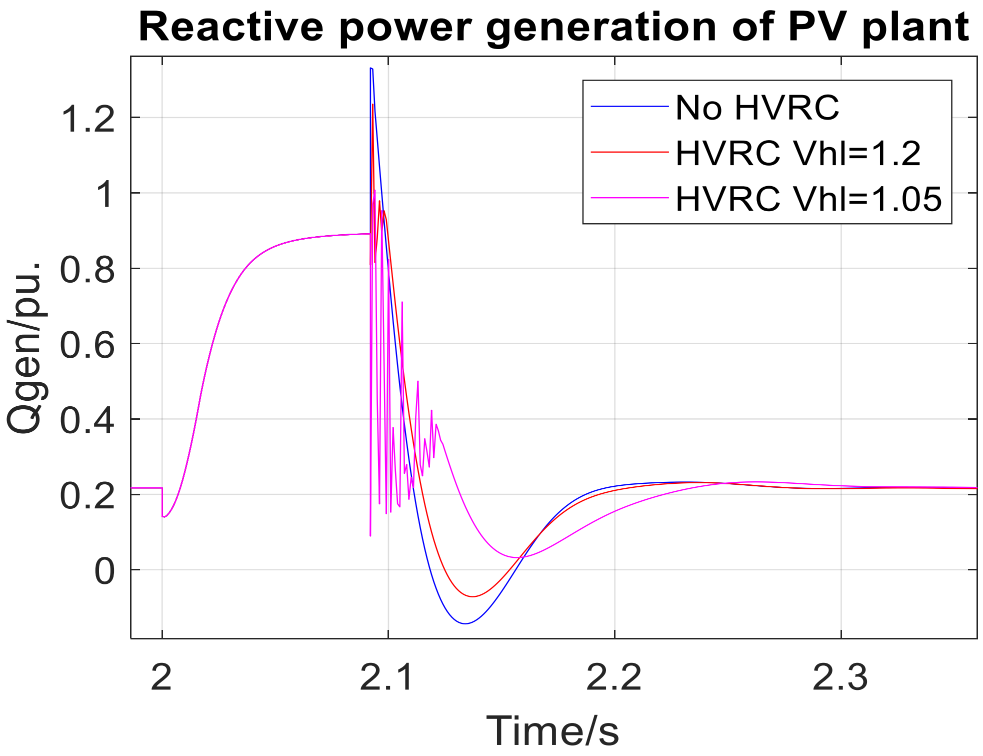


Block diagram of PV converter model

Case study – Dynamic response

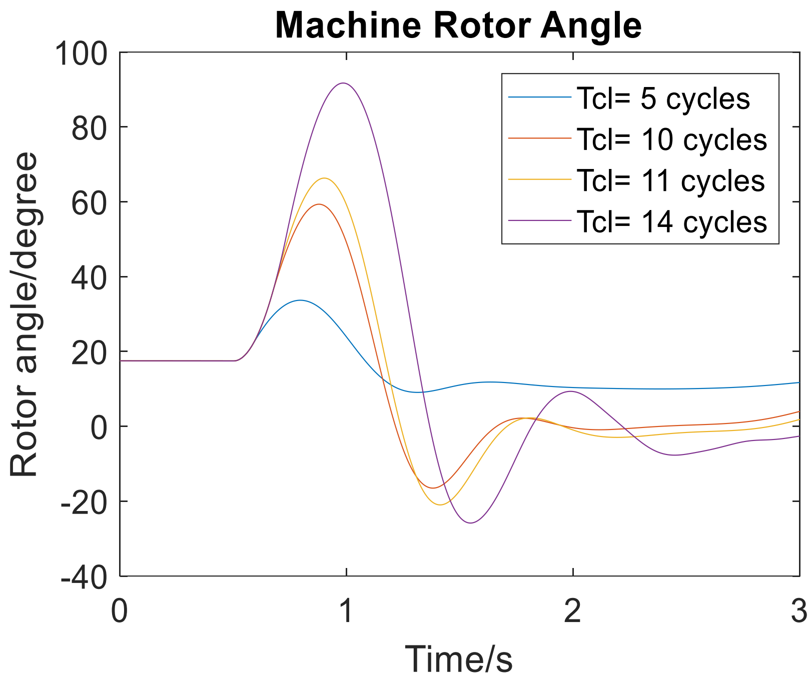
- High voltage reactive current management (HVRCM) in the converter model aims to limit reactive current injection under high terminal voltage conditions.
- Adjust the threshold voltage of HVRCM to improve the transient overvoltage issues.



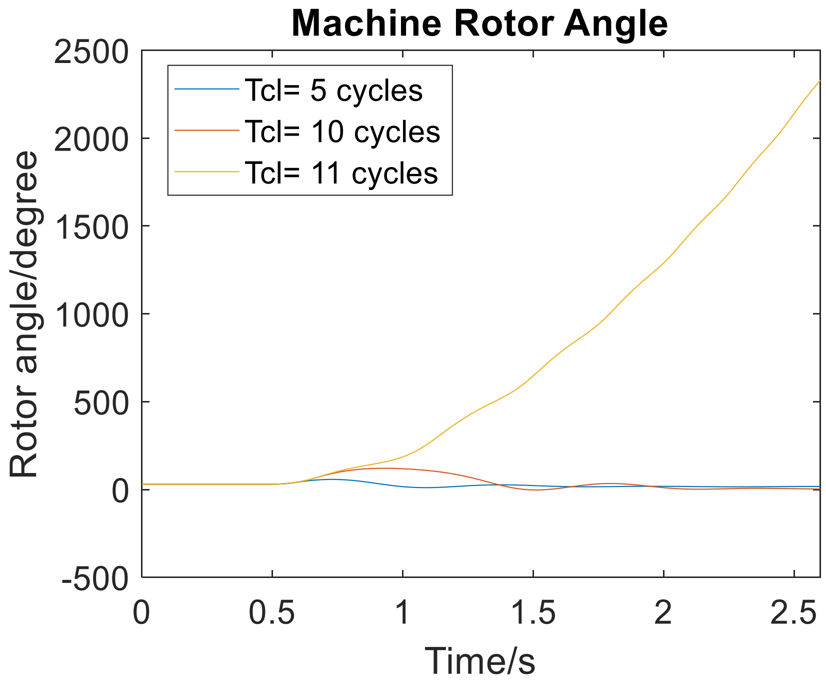


Case study – Transient Stability

- A three-phase branch fault cleared with different clearing times is simulated in the gas scenario and PV scenario.
- Gas plant provides more reactive power support during the fault, which results in higher bus voltages and more synchronizing power output from generators.



Gas scenario



PV scenario

Conclusion

- Impacts of PV generation and natural gas-fired generation on the steady state and dynamic behavior of large-scale power systems are studied.
- Higher penetration of PV generation result in a lower short circuit level (less fault current contribution).
- Less reactive power capability provided by the PV generation could result in smaller voltage stability margins.
- Conventional gas-fired generation provide more reactive power support during fault conditions which could result in to higher voltages during fault and contribute to transient stability.