NREL is a national laboratory of the U. S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Impact of Aggregated PV on Subsynchronous Torsional Interaction

Rasel Mahmud, Andy Hoke, Jonathan White
National Renewable Energy Laboratory

Introduction

This paper investigates induced oscillation (specifically subsynchronous torsional interactions, SSTI) in power systems arising from photovoltaic (PV) power modulation. Time domain simulations of a modified IEEE benchmark power system are analyzed to <u>determine whether PV inverters, especially those in volt-var control mode, could impact SSTI</u>. In the IEEE benchmark system, a PV generator was added at the same bus where the synchronous generator is connected. The impact of different parameters of the PV inverters' volt-var curve on SSTI is examined. The most severe impact found arises from the time response of the inverter's reactive power change. A second-order time response with natural frequency matching the rotor speed deviation oscillation frequency and low-damping ratio quickly drives the system to an unstable region. Although it is highly unlikely that conditions necessary for distributed energy resource-induced oscillations would occur in the field, with knowledge of this vulnerability in mind, inverters' control parameters can be designed to avoid it.

Model Background

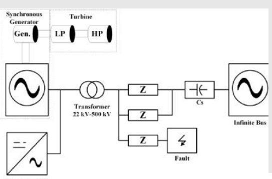

Fig. 1. Modified IEEE first-benchmark model for testing SSTI induced by aggregated PV

- **The IEEE benchmark system was modified by adding a PV generator at the same bus where the synchronous generator is connected.**
- **SSTI triggered by a disturbance, such as a fault in the transmission line, especially in a series-compensated line**

Damping SSTI with Aggregated PV

R. K. Verma et al [1] showed that a PV plant can be used as a PV static synchronous compensator to mitigate SSR.

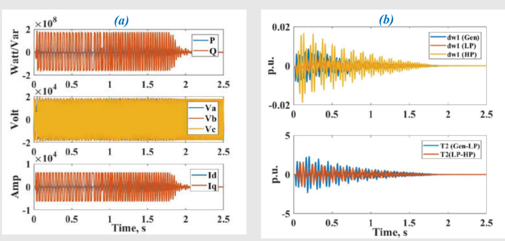

Fig. 2. SSTI mitigation using aggregated PV: (a) power, voltage, and current measurements of aggregated PV output; and (b) synchronous generator response; the top curve shows the rotor speed deviations of different masses of the synchronous generator, and the lower plot shows the torques, in p.u., transmitted from the generator to the low-pressure side of the turbine, and from the low-pressure side turbine to the high-pressure side of the turbine.

Impact of Volt-var Control on SSTI

- ***We investigate the effects of other PV reactive power modulation techniques on the SSTI.***
- ***A widely adopted method for PV reactive power regulation is volt-var control***
- ***The impact of horizontal shifts of the volt-var curve deadband along the voltage axis and vertical shifts of the volt-var deadband along the VAR axis are examined.***

Impact of Volt-var Control on SSTI

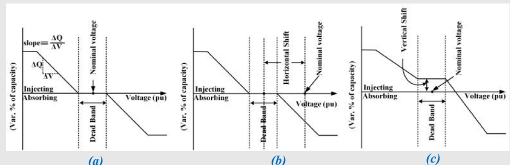

Fig. 3. Different volt-var curves: (a) regular volt-var curve, (b) horizontal shift of deadband from nominal voltage along the voltage axis, and (c) vertical shift of deadband along the var axis

Baseline Volt-var Modulation

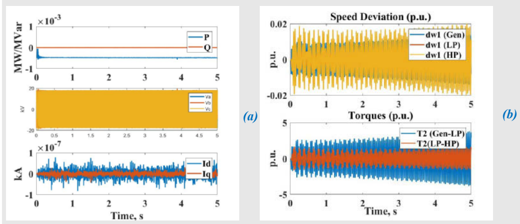

Fig. 4. Baseline case when the aggregated PV is not generating or absorbing any power: (a) power, voltage and current measurements of aggregated PV output and (b) synchronous generator response

Worst-Case Analysis

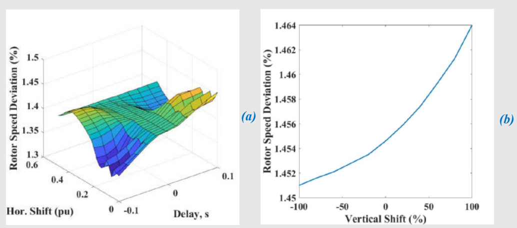

Fig. 5. Worst case analysis a) Impact of shifting volt-var curve horizontally and changing volt-var controller delay time on rotor speed deviation b) Impact of shifting volt-var vertically on rotor speed deviation

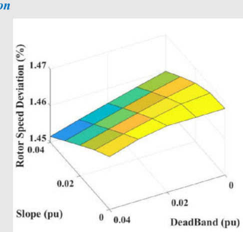

Fig. 6. Impact of change of volt-var deadband and slope on rotor speed deviation

Examination of Fig. 5 and Fig. 6 shows that although different values of the parameters defining the volt-var curve have different impacts on the rotor speed deviation, <u>the maximum rotor speed deviation does not greatly change for any of these settings.</u>

Worst-Case Analysis

Impact of Volt-var Time Response

- **It was previously observed by the authors that the volt-var time-domain dynamics of some commercially available inverters can be modeled with reasonable accuracy using second order of time responses:**

$$H(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n + \omega_n^2}$$

where ω_n, and ξ are the natural frequency and damping coefficient of the response, respectively.

- **The simulations find that if the natural frequency of the second-order time response matches the frequency of the rotor speed deviation, the resulting SSTI could cause the synchronous machine to become unstable.**

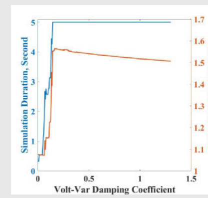

Fig. 7. Impact of damping coefficient in the second-order time response on rotor angle stability. (Shorter simulation durations indicate increased unstable oscillations.)

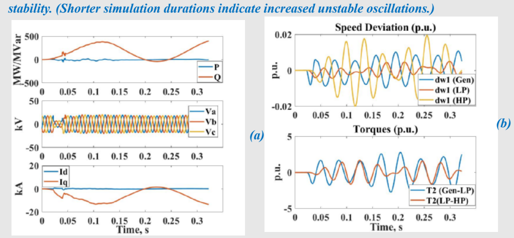

Fig. 8. Simulation result when the natural frequency of aggregated volt-var response matches rotor speed deviation frequency (25.12 Hz) with a volt-var damping coefficient of 0.005

Conclusions

The following observations were made:

- **Different parameters of volt-var curves have different levels of impact on SSTI**
- **The most severe impact found so far arises from the time response of reactive power change; a second-order time response with natural frequency matching the rotor speed deviation oscillation frequency and low damping ratio drives the system quickly to an unstable region. Such low damping ratios are unlikely in practical inverters.**
- **Although this research identified a potential impact of aggregated PV on the stability of the electric grid, especially on the ability of aggregated PV to induce oscillations in the power system, the work was limited in scope, and findings should be considered preliminary.**

References
[1] R. K. Varma and R. Salehi, "SSR Mitigation With a New Control of PV Solar Farm as STATCOM (PV- STATCOM)," *IEEE Transactions on Sustainable Energy*, vol. 8, pp. 1473–1483, oct 2017.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

The Virtual 47th IEEE Photovoltaic Specialist Conference (PVSC)
June 15th, 2020
NREL/PO-5D00-76904