PMU-based Dynamic Coordinated Voltage Control of a Distribution System with FACTS and Storageless PV Participation

Rereloluwa Fatunmbi
Dr. Ghadir Radman, Research Advisor

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Abstract

This research is motivated by the need for optimal voltage regulation in distribution systems with renewable energy sources independent of energy storage. While extensive enquiry has been conducted in voltage regulation for distribution systems, relatively little has been done as far as deploying big data obtained from phasor measurement units (PMUs) for voltage control. In this study, we implement coordinated voltage control by using the time-stamped voltage data from the synchrophasors to determine the operating state (normal, fluctuating, or contingency states) of the network. With this, we harmonize the interaction between the PV inverters, on-load tap changer, and other FACTS devices to ensure an improved regulation that is independent of energy storage compensators. We use the test distribution system in figure 1 to validate our results by simulation on OpenDSS and PSCAD.

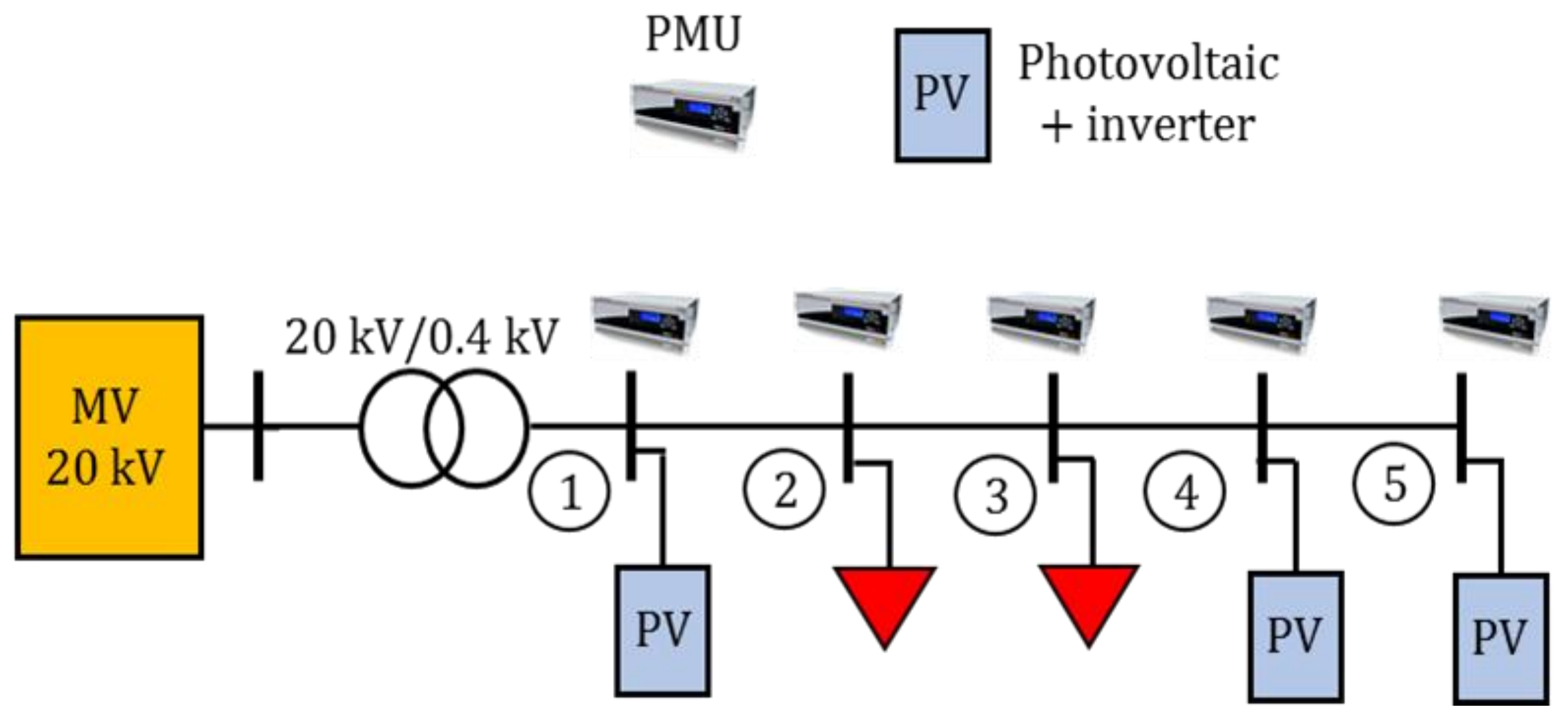

Fig. 1: Test distribution grid

Objectives

- Demonstrate how PMU big data used for voltage regulation can improve power quality.
- Coordinate control between the on-load tap changer, PV inverters, and a STATCOM.
- Implement active power dependent voltage control ($Q(P)$) for the three different operation states of the system.
- Provide a comparative analysis by simulation of the control method proposed in this paper with other recent methods published in literature.

Methodology

The equation below shows how reactive and active power influence changes in bus voltage [1],[2].

$$\frac{dV}{V_S} = \frac{P.R+(\pm Q.X)}{|V_S|^2}$$

From this equation, we obtain the contour plot in figure 2. We can deduce from the slopes of the contours that the voltage is affected more by active power than reactive power. In figure 3, we observe that the bus 5 voltage is most affected by step increments in injected active power to the distribution network. This therefore justifies the importance of an active power dependent voltage control. Furthermore, the result explains why bus 5 should be treated as the target bus for voltage regulation.

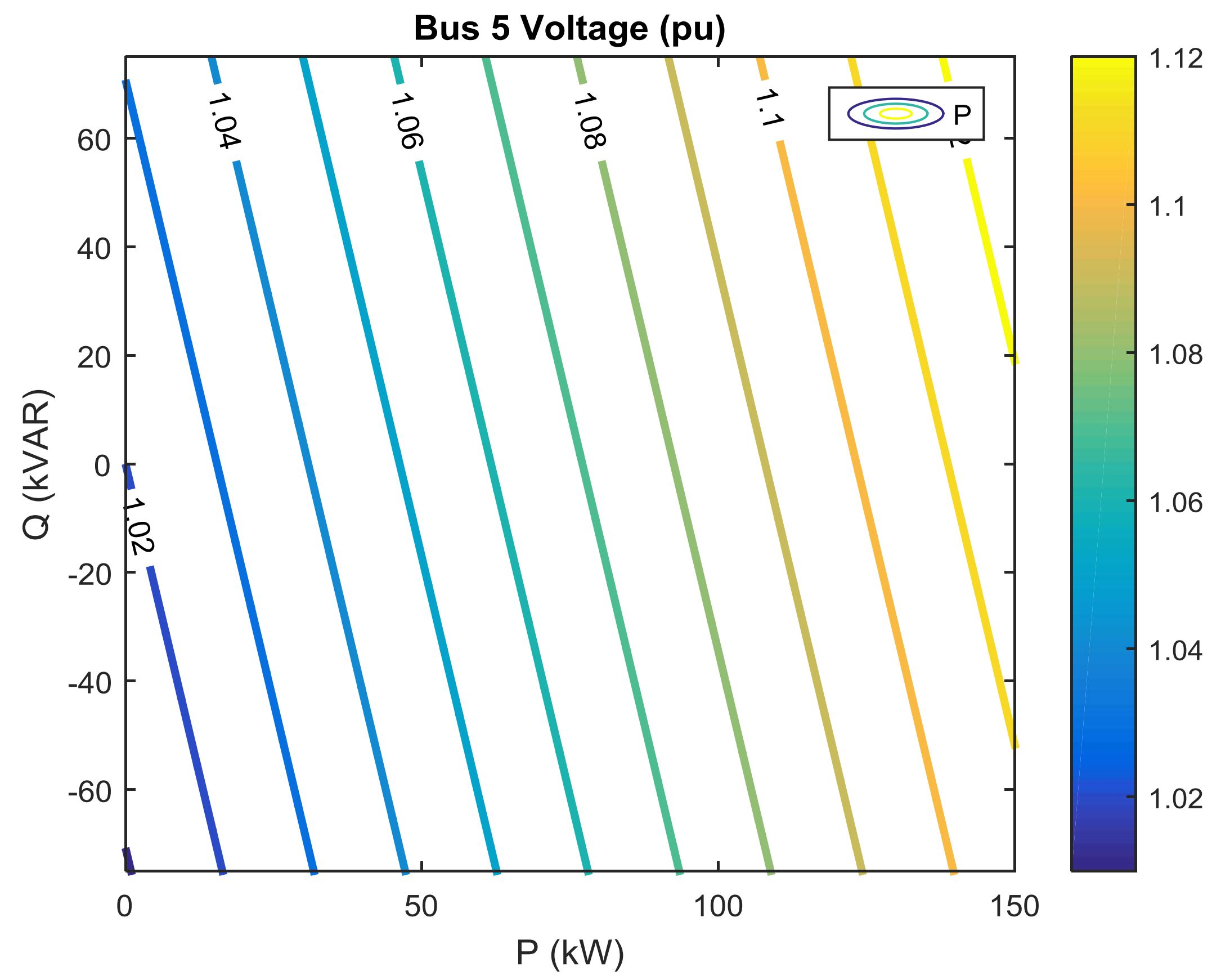

Fig. 2: Variation of bus 5 voltage with power

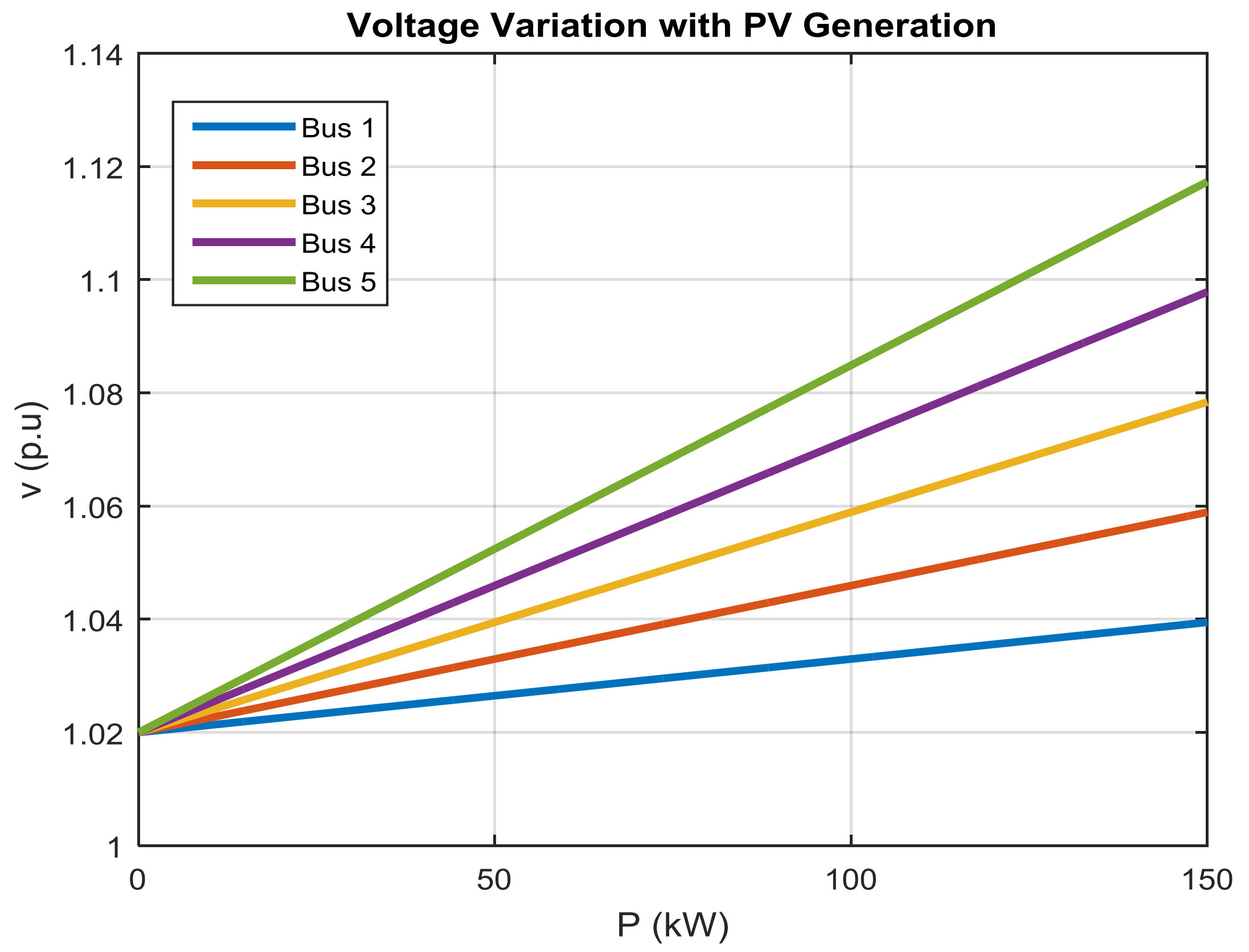

Fig. 3: Variation of bus voltages with PV power

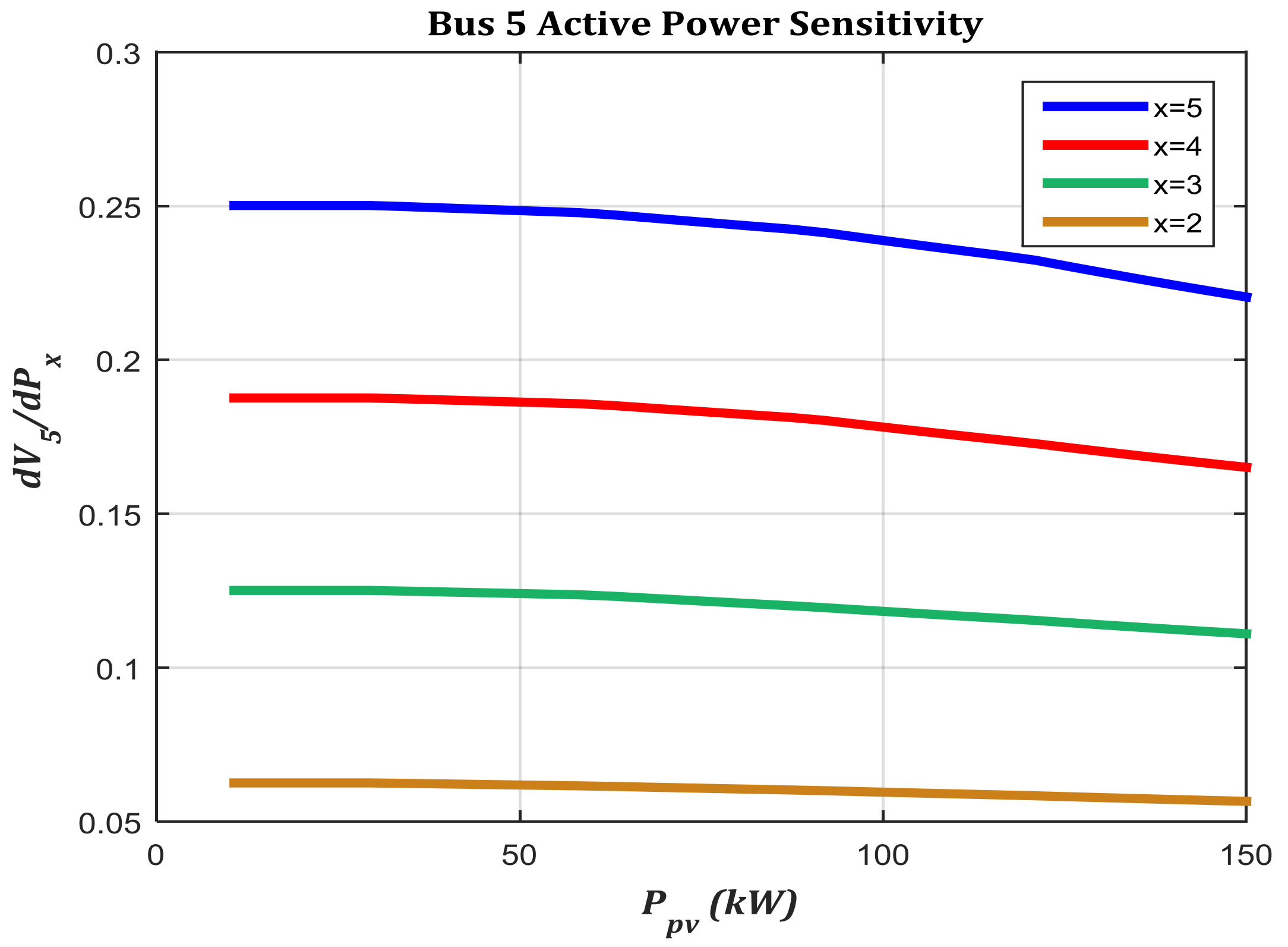

Fig. 4: Sensitivity of bus 5 voltage to active power

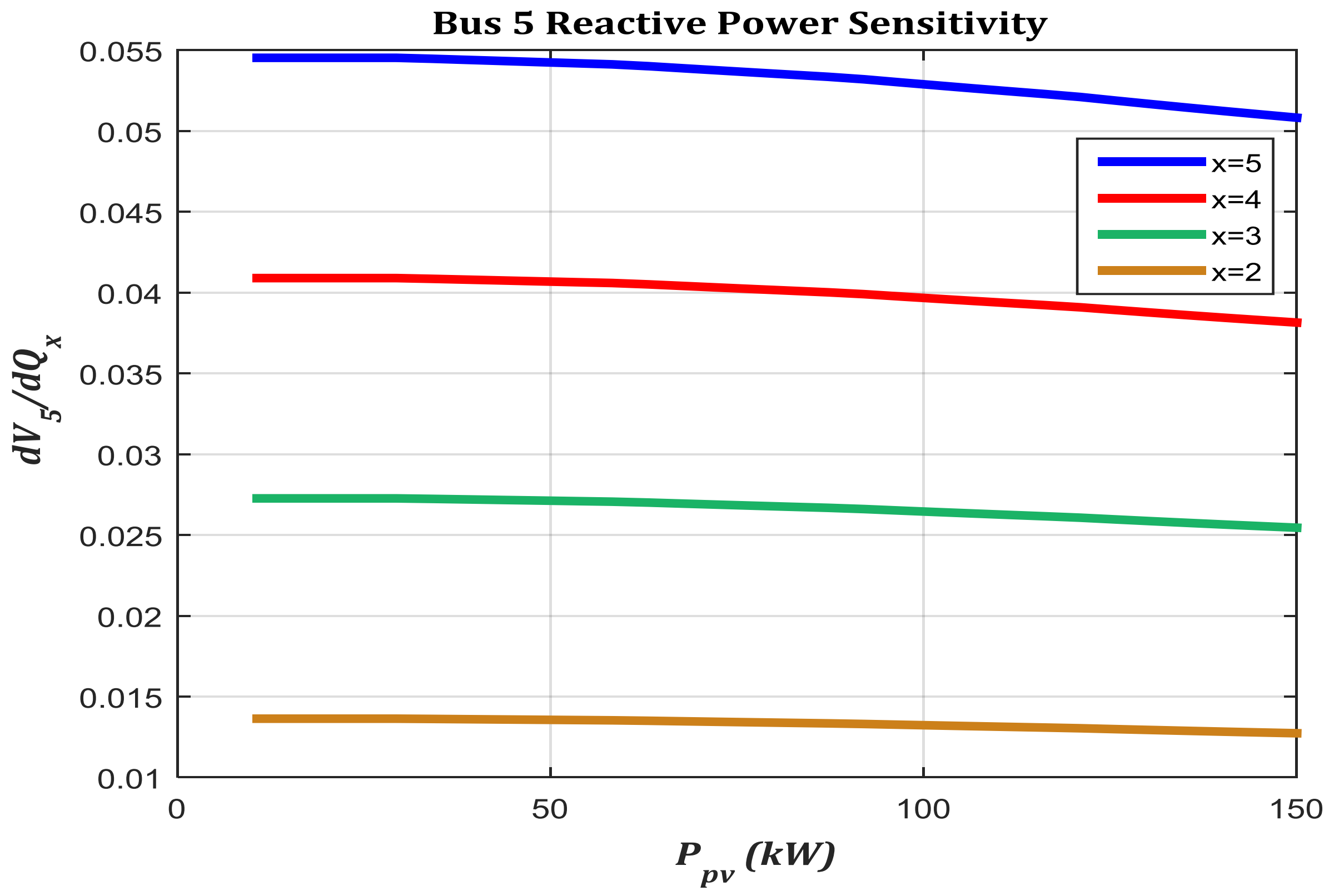

Fig. 5: Sensitivity of bus 5 voltage to reactive power

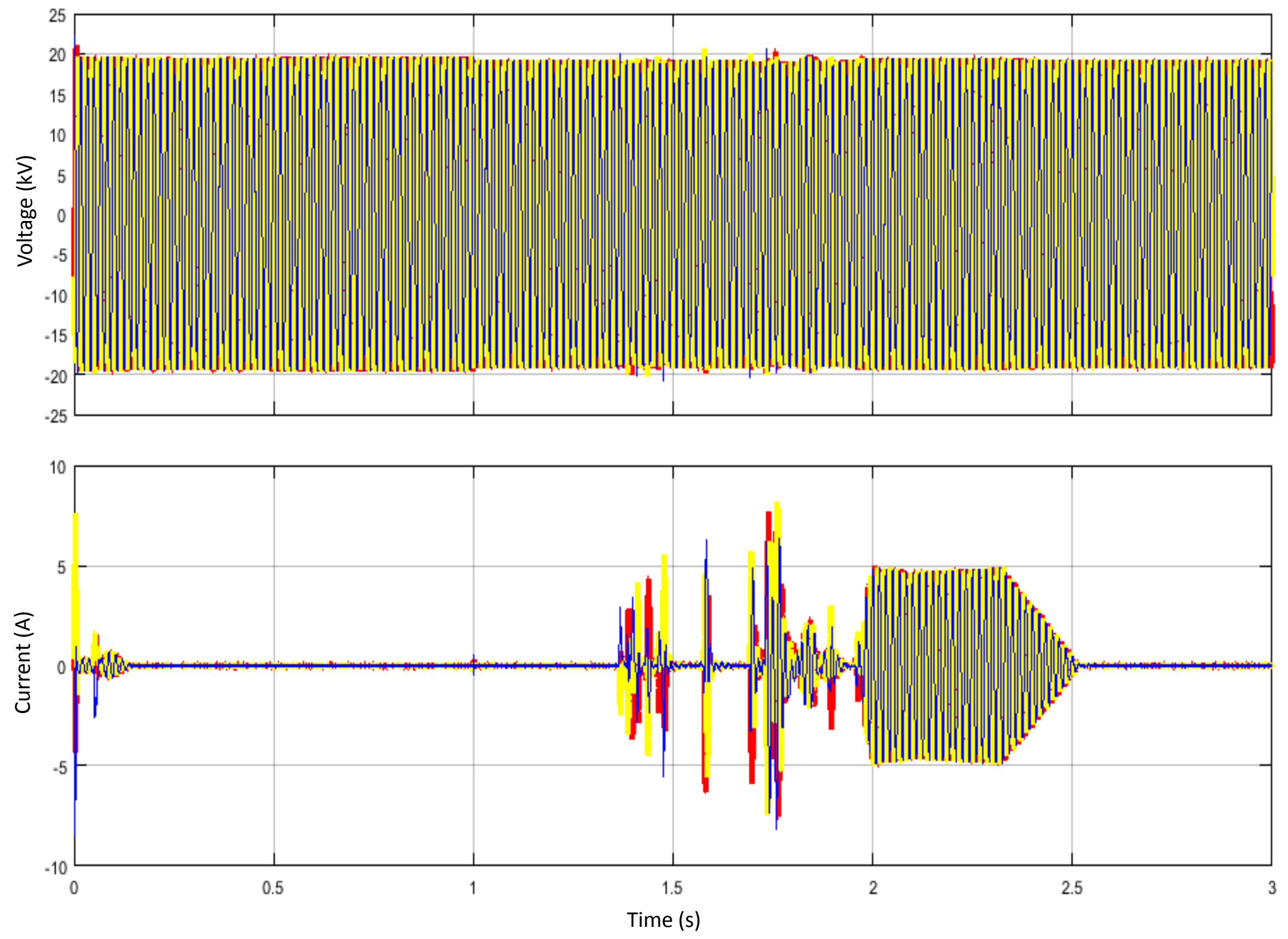

Fig. 6: Voltage and Current profile for bus 3

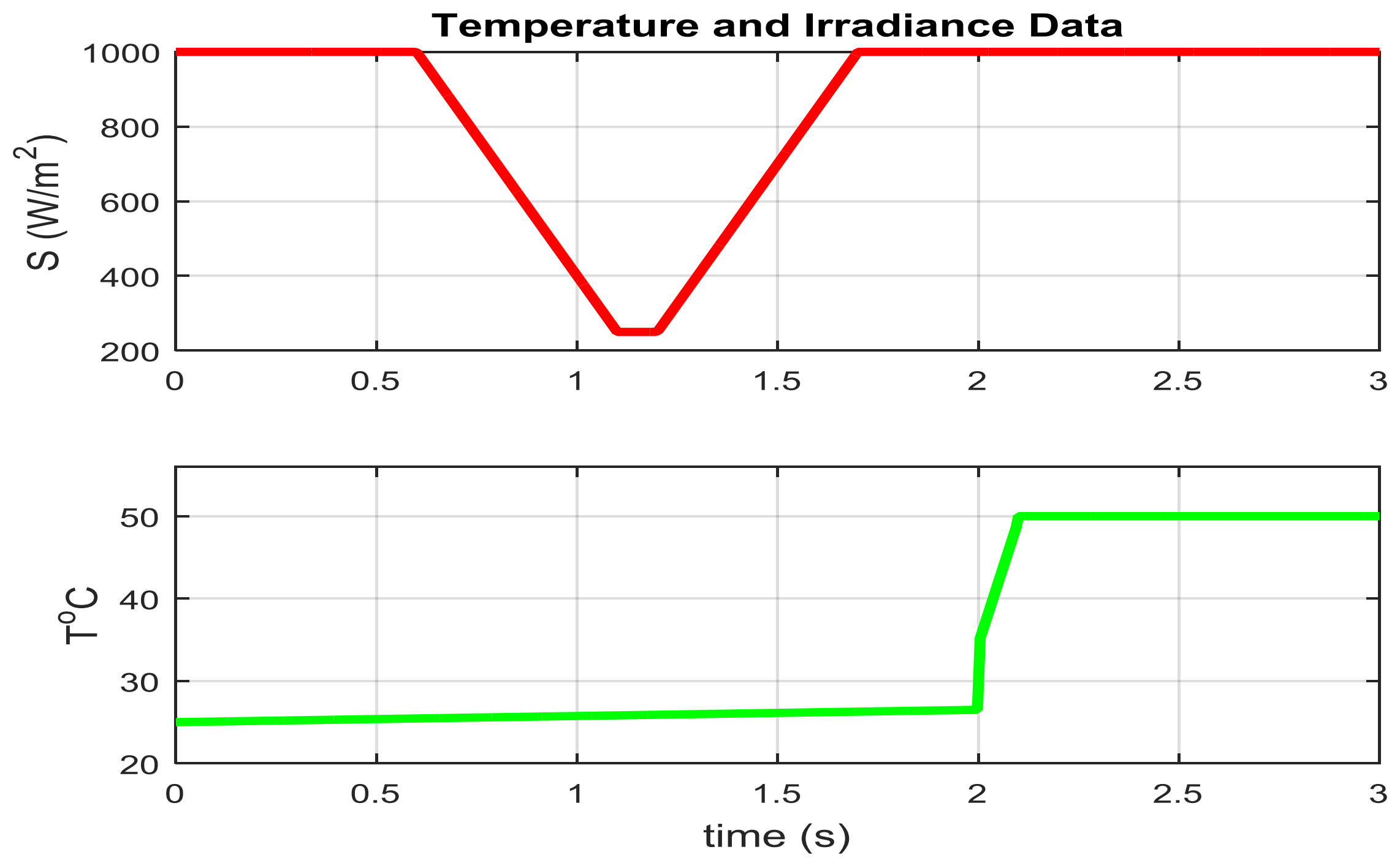

Fig. 7: Solar insolation and temperature

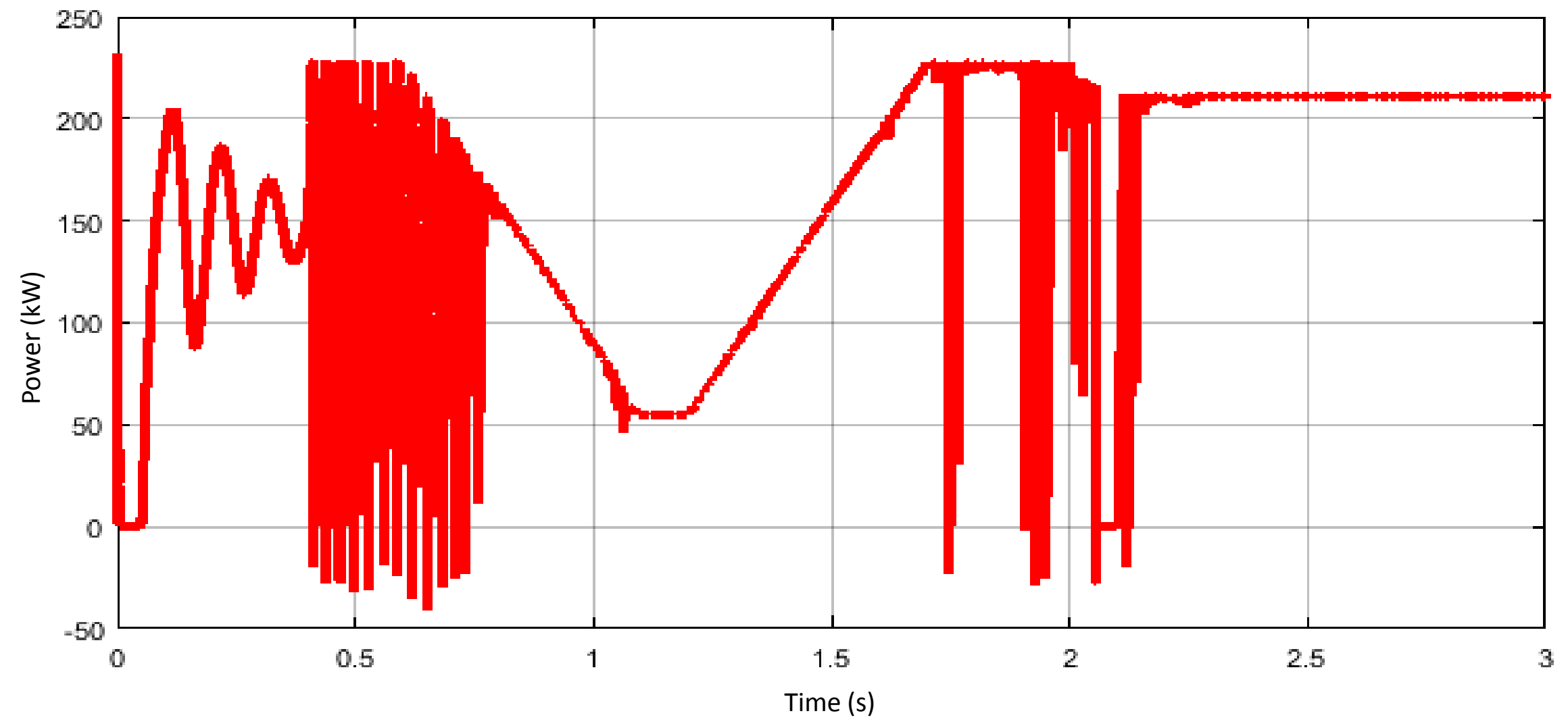

Fig. 8: Active Power from PV 4

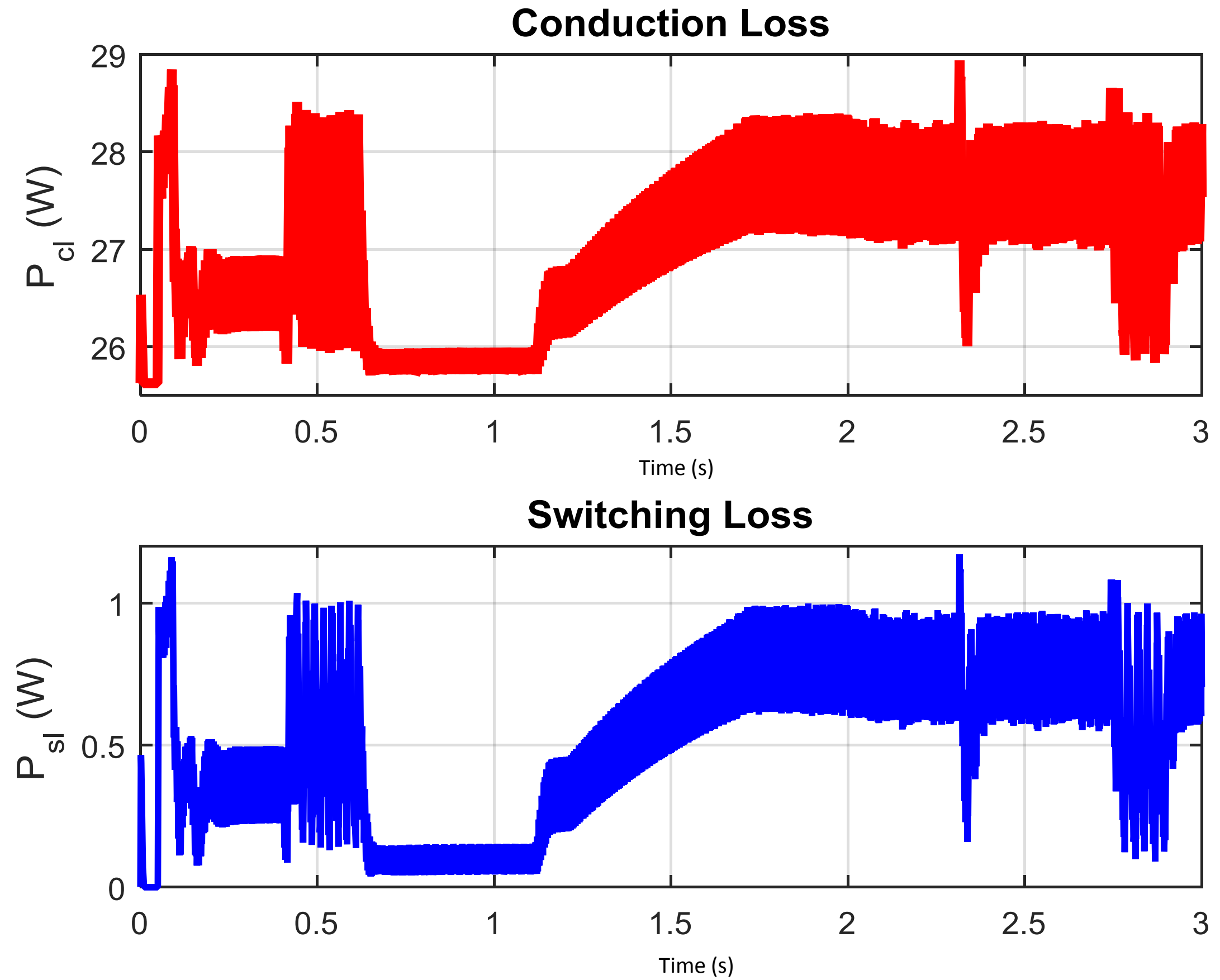

Fig. 9: Conduction and switching losses of inverter 4

Figures 4 and 5 are the voltage sensitivity plots to active and reactive powers respectively, for the buses as injected active power is increased. We can clearly see bus 5 consistently has the highest sensitivity. Furthermore, we observe an almost constant sensitivity as PV power changes. It is due to this quasi-static nature, that we can define a coordinated control algorithm based on these voltage sensitivity constants. Comparing figures 4 and 5, it is observed that the sensitivity to active power is much higher than to reactive power. This is due to the fact that in distribution networks, the lines have a high resistance to reactance ratio.

Figures 6 to 9 show the waveforms obtained from the dynamic simulation of the distribution system in figure 1. In figure 9, we see the influence the solar irradiation profile has on the switching and conduction losses of the PV inverter. In our coordinated control, we desire to minimize these losses among our other objectives.

Conclusion and Future Work

Since we have shown the degree by which PV power changes affect the bus voltages of a distribution system, we proceed by implementing a control strategy that ensures voltage regulation in all stages of operation.

References

[1] L. Xie, Y. Chen and H. Liao, "Distributed Online Monitoring of Quasi-Static Voltage Collapse in Multi-Area Power Systems," in IEEE Transactions on Power Systems, vol. 27, no. 4, pp. 2271-2279, Nov. 2012.

[2] T. Stetz, F. Marten and M. Braun, "Improved Low Voltage Grid-Integration of Photovoltaic Systems in Germany," in IEEE Transactions on Sustainable Energy, vol. 4, no. 2, pp. 534-542, April 2013.

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