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Voltage Collapse and ODE Approach to Power Flows: Analysis of a Feeder Line with Static Disorder in Consumption/Production

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We consider a model of a distribution feeder connecting multiple loads to the sub-station. Voltage is controlled directly at the head of the line (sub-station), however, voltage anywhere further down the line is subject to fluctuations, caused by irregularities of real and reactive distributed power consumption/generation. The lack of a direct control of voltage along the line may result in the voltage instability, also called voltage collapse - phenomenon well known and documented in the power engineering literature. Motivated by emerging photo-voltaic technology, which brings a new source of renewable generation but also contributes significant increase in power flow fluctuations, we reexamine the phenomenon of voltage stability and collapse. In the limit where the number of consumers is large and spatial variations in power flows are smooth functions of position along the feeder, we derive a set of the power flow Ordinary Differential Equations (ODE), verify phenomenon of voltage collapse, and study the effect of disorder and irregularity in injection and consumption on the voltage profile by simulating the stochastic ODE. We observe that disorder leads to nonlinear amplification of the voltage variations at the end of the line as the point of voltage collapse is approached. We also find that the disorder, when correlated on a scale sufficiently small compared to the length of the line, self-averages, i.e. the voltage profile remains spatially smooth for any individual realization of the disorder and is correlated only at scales comparable to the length of the line. Finally, we explain why the integrated effect of disorder on the voltage at the end of the line cannot be described within a naive one-generator-one-load model.

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