Robustness Estimation of the Seismic-Damaged Electric Power System in the Context of Failure Propagation

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INTRODUCTION

Electric power system is a highly complex network consisting of diverse sub-sectors that are spatially distributed and interconnected each other. As such, during an earthquake, it is common that the system encountered problems in maintaining reliable operation because each sub-sector can be counted as a hazard source. In this context, many researchers proposed measures to estimate infrastructure reliability under given earthquake scenario and thus it can be relatively easier to attain reliability of each sub-sector in the power system (i.e., power plant, transmission substation and distribution substation). However, the reliability can only deal with a common-cause failure such as destruction of the power plant through earthquake ground shaking. A cascading failure (e.g., malfunctions of substations and water treatment plants that require electricity for operating) and an escalating failure (e.g., delay in repair activities and the excess demand) are the matter of the robustness. Therefore, it is required that the research perspective shifts from reliability (i.e., expected performance at given conditions such as sufficient resources and constant demand) to robustness (i.e., actual performance at uncertain conditions such as supply chain disruptions and demand fluctuation). To address these issues, this paper aims to determine the possible factors driving uncertainty in robustness estimation and how they related to the system failure. More specifically, the electric power system robustness estimation model under an earthquake scenario is developed using system dynamics approach.

MODEL STRUCTURES

For the analysis of the power system, this research considered two types of stocks: intermediary product and final product. An intermediary product is the output from a sub-sector becoming the input to another sub-sectors (i.e., "*345kV electricity*" and "*154kV electricity*"), while the final product (i.e., "*22.9kV electricity*") is the last output of power system for delivering to end-user. One of the important variables in our model is "*reliability*". In the pre-disaster phase, the reliability of all sub-sectors equal one. Thus, each sub-sector can operate properly to meet its original capacity and there is the balance of expected output in supplier-side (i.e., "*delivered electricity to customer*") and usable output for customer-side (i.e., "*hourly electricity demand*"). In turn, "*robustness*" also equals one. When an earthquake occurs, however, each sub-sector may have reduced level of ability to generate or transmit electricity. Moreover, if a sub-sector needs intermediate output from upper supply chain as its input, the conversion rates depends on delivered electricity from another sub-sector. For example, although the original capacity of transmission substation is 50MW per hour, hourly transformed 154kV electricity is lower than 50MW if delivered 345kV electricity from power plant is not sufficient. Another issues can arise in abnormal conditions is "*shortage of production factors*" (R1), "*mandatory electricity restriction*" (B1), "*existing power system restoration*" (R2), and "*newly installed power system*" (B2). In any case, such factors intensify uncertainty and make challenges to estimating the electric power system robustness after an earthquake.

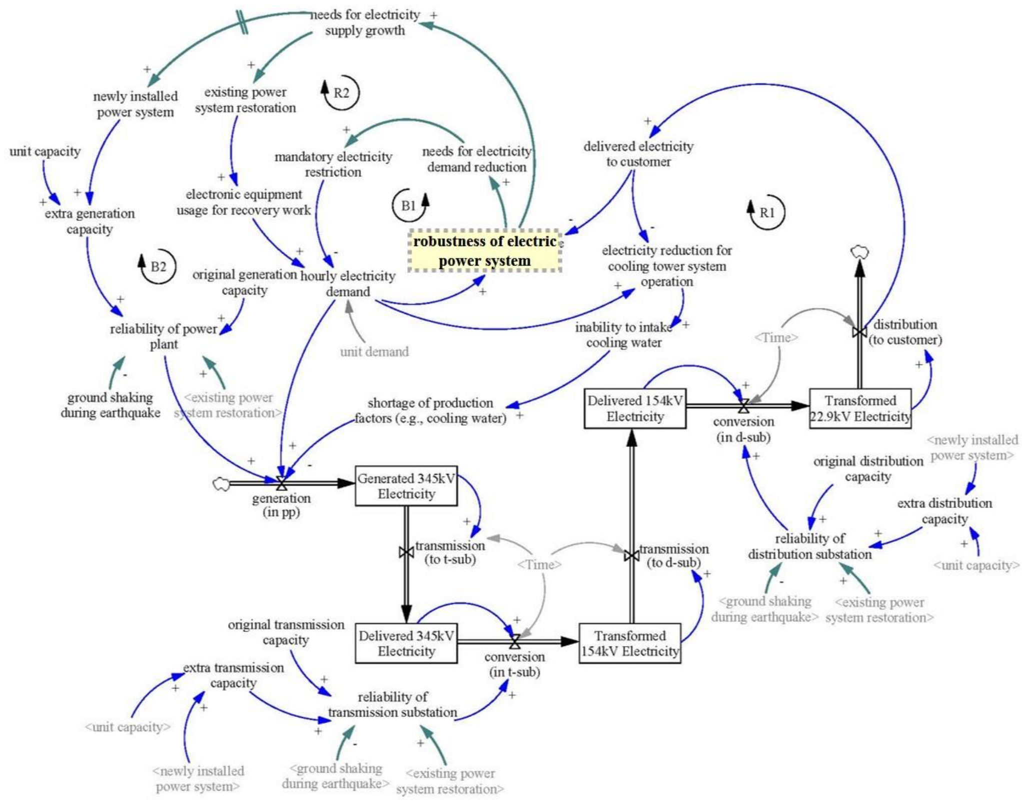

Figure 1. Entire model for seismic-damaged power system robustness estimation

SIMULATION RESULTS AND DISCUSSIONS

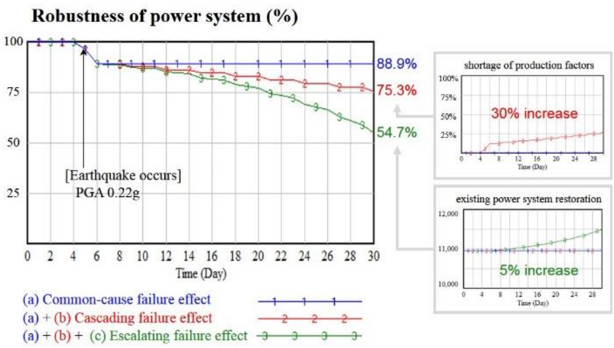

Figure 2. What kinds of failures occur during an earthquake? And how they propagate?

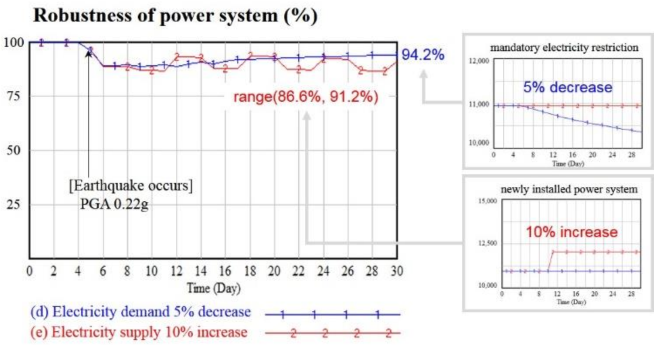

Figure 3. Which is better for robustness, a supply growth or a demand reduction?

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