Interrelation of structure and operational states in cascading failure of overloading lines in power grids

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Interrelation of Structure and Operational States in Cascading Failure of Overloading Lines in Power Grids

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***Abstract*—As the modern power system is expected to develop to a more intelligent and efficient version, i.e. the smart grid, or to be the central backbone of energy internet for free energy interactions, security concerns related to cascading failures have been raised with consideration of catastrophic results. The researches of topological analysis based on complex networks have made great contributions in revealing structural vulnerabilities of power grids including cascading failure analysis. However, existing literature with inappropriate assumptions in modeling still cannot distinguish the effects between the structure and operational state to give meaningful guidance for system operation. This paper is to reveal the interrelation between network structure and operational states in cascading failure and give quantitative evaluation by integrating both perspectives. For structure analysis, cascading paths will be identified by extended betweenness and quantitatively described by cascading drop and cascading gradient. Furthermore, the operational state for cascading paths will be described by loading level. Then, the risk of cascading failure along a specific cascading path can be quantitatively evaluated considering these two factors. The maximum cascading gradient of all possible cascading paths can be used as an overall metric to evaluate the entire power grid for its features related to cascading failure. The proposed method is tested and verified on IEEE30-bus system and IEEE118-bus system, simulation evidences presented in this paper suggests that the proposed model can identify the structural causes for cascading failure and is promising to give meaningful guidance for the protection of system operation in the future.**

***Index Terms*—Cascading Failure, Complex Network, Cascading Path, Cascading Drop, Cascading Gradient**

1. INTRODUCTION

As one of the most important public facilities, power system plays a critical role for modern society and economy. With great development in information and control technologies, it is expected to be upgraded to a new generation, i.e. smart grid or energy internet. However, on the other hand, failures in power system may cause more and more catastrophic consequences as observed from several historical outages in US and Europe [1]. Based on the analysis of historical records, cascading failures can make more serious impacts on social economy and living [2].

Cascading outage or failure is a sequence of events in which an initial disturbance, or a set of disturbances, triggers a sequence of one or more dependent component outages [2].The propagation process of cascading failure is very complex by involving power transmission and distribution, protection system, control system, information system and even human decision-making process. Therefore, although people have made great progress in revealing mechanism of cascading failure and mitigate its risks [2]-[13], there are still no ultimate solutions. Although some of these methods have considered the problem based on both real operational states and structural factors for evaluation, the impact of states and structures have not been clearly distinguished and quantitatively evaluated respectively. Furthermore, it is still difficult for them to overcome the heavy computation burden and stochastic causal relations.

After the investigation of small-world [14] and characterization of scale-free networks [15] in power grids, complex networks(CN) have been widely studied for the analysis about power grid security [16]-[20].Meanwhile, CN is also popularly applied in studying cascading failures of network systems including power grids. For isolated networks, the study of cascading failure in CN mainly falls into two categories [21]: first, failures due to network overload when the network flow is a physical quantity; second, models based on local dependences, such as the decision-making process of interacting agents. Furthermore, as many network systems are tightly related, a research framework for robustness of interdependent networks was also proposed [21]. As discussed above, the real cascading process of power grids is very complicated by involving different interdependent systems.

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