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HIERARCHICAL MODELING AND HIGHLY TRUSTED VERIFICATION METHODS FOR COMPLEX SPACECRAFT ELECTRICAL POWER SYSTEMS

Abstract

As the key subsystem of the spacecraft, the electrical power system is the lifeline of the spacecraft. Its reliability and safety are directly related to the success of the missions. With the increasing complexity, power capacity and scales of spacecrafts represented by space stations and deep space exploration spacecrafts, it brings great challenges to the design and verification of spacecraft electrical systems. It is necessary to carry out full-level, entire lifecycle, and highly trusted design and verification to ensure that "correct design at the first time" and "highly safe and reliability" for the electrical power system. The electrical system is a typical multi-level system, including system level, equipment level, circuit level, etc. Besides, it is closely coupled with orbit, space environment, flight mission. it covers the multi elements such as energy balance, grounding loop, power generation capacity, bus dynamic response, failure characteristics, attenuation etc. Based on the multi-level and multi-element characteristics of the spacecraft electrical system, this paper analyzes the problems involved in the modeling and verification of the complex electrical system. First, a hierarchical modeling method based on cyber-physical fusion characterization is proposed to achieve multi-level "digital maps" modeling. Reliability characteristics and failure mode of key electrical components and system fault propagation mechanism are considered in the models. The model equivalent reduced-order method is applied to reduce complexity of models. Second, the reliability optimization of the spacecraft electrical power system is analyzed based on the hierarchical models. Third, the data-driven virtual and real combination offline model identification and trusted verification method of spacecraft electrical system is proposed to ensure the accuracy of the model and verify the unmeasurable elements in the ground tests. Furthermore, On the basis of the offline model and limited on-orbit telemetry data, on-orbit state estimation and performance prediction method are proposed based on the dynamically modified model. The online estimation of electrical system state is realized by rolling time window estimation method, and the model mismatch is dynamically compensated by Gaussian process optimization method to achieve accurate estimation and prediction of system state. Finally, an example of modeling and verification of the spacecraft electrical power system is provided to verify the effectiveness of the proposed methods. In the future, the proposed methos can be applied in complex spacecraft electrical system such as manned moon landing, deep space bases, etc.