FTA기법을 이용한 하이브리드 전력변환시스템 신뢰성 분석

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Reliability analysis of hybrid power conversion systems by a fault tree analysis approach

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ABSTRACT

This paper performs reliability and Mean Time to Failure (MTTF) analysis for hybrid Power Conversion Systems (PCS). Those systems include by Maximum Power Point Tracking algorithm (MPPT) implemented in a Photovoltaic (PV) cell a DC-DC boost converter, an energy storage system (ESS) in an isolated DC-DC converter, the Polymer Electrolyte Membrane Fuel Cell (PEMFC) stack as a DC source through an isolated DC-DC converter. All three converters are parallel to a single-phase inverter. These analyses are provided using the Fault Tree Analysis (FTA) approach under worst-case operating conditions and highlight the significant impact of reliability on the entire system, starting from a component in the power electronic circuit. Finally, it is verified on a small-scale graph.

1. Introduction

The residential sector accounts for a significant portion of the global energy demand. In the contemporary era of technological advancement, the concept of a Home Energy Management System (HEMS) has emerged as a pivotal solution to the growing concerns over energy efficiency. Energy management technologies for residential are needed because energy consumption in residential and commercial buildings is about 22% of the grid and is gradually increasing[1]. The main point of this system configuration by the hybrid Power Conversion System (PCS), a sophisticated amalgamation of various energy sources and conversion designed to optimize energy usage within the residential.

In this paper, we will propose a reliability analysis of hybrid PCS by separating three parallel DC-DC converter systems and different power sources respectively and all three systems are parallel to a single-phase inverter for home energy management system between the grid and energy storage in the residential. For the reliability analysis and evaluation by using the Fault Tree Analysis (FTA) approach, the failure rate considering the operation of the hybrid PCS and quantitatively present the Mean Time to Failure (MTTF).

2. Proposed circuit of hybrid PCS

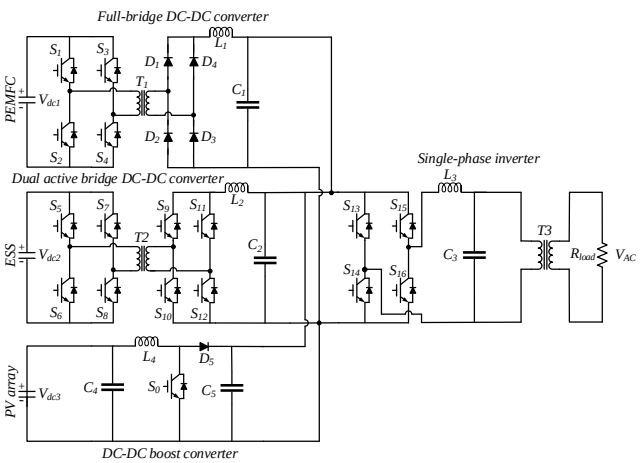

Fig.1 The circuit of hybrid PCS.

The first circuit of hybrid PCS is a DC-DC boost converter, which implements the Maximum Power Point Tracking (MPPT) algorithm and includes power source input from the Photovoltaic (PV) cell array connected (145V). The MPPT optimizes the output power of the PV by tracking the maximum power point under various operating conditions. The second circuit is a full-bridge DC-DC converter isolated by a transformer and provides the power source depending on the Polymer Electrolyte Membrane Fuel Cell (PEMFC) stack (50V). The next circuit is a Dual Active Bridge (DAB) DC-DC converter, it can count on the type of isolated DC-DC converter and will get a power source from a household Energy Storage System (ESS) (50V). All three types of DC-DC converter will parallel each other. In this category, the circuit converter will step up the voltage to 400VDC. The last circuit in the hybrid PCS is taken from 400VDC into a single-phase inverter to get the voltage amount of 220VAC. To secure the output of the inverter would be 5kW, and each DC-DC convert output would be 5kW also. As shown in Fig. 1, the proposed hybrid PCS combines each circuit.

2.1 Reliability analysis with FTA approach

FTA is a method for reliability analysis, estimation, and

design of complex systems, revealing weak links and sub-basic events up to the top event. To calculate the possible system failure, we must follow the reliability block structures (parallel or series structures), AND or OR gates, and the value of the basic events[2]. However, the value of basic events can be a probability value or failure rate depending on that system's evaluation. In this paper, we will focus on the failure rate of every component device in the hybrid PCS and calculation according to the MIL-HDBK-217F for reliability prediction of electronic equipment[3]. Finally, obeying the rules of FTA is drawing the top event until it ends up with the basic event, FTAs of hybrid PCS as shown in Fig. 2.

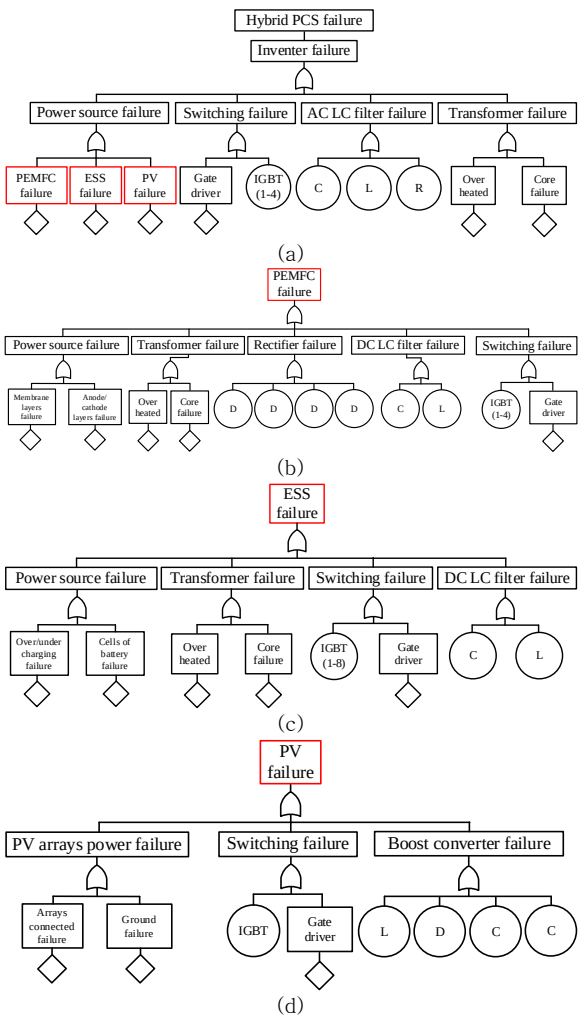

Fig.2 The proposed FTA of hybrid PCS, (a) The whole system of hybrid PCS failure, (b) PEMFC failure branch, (c) ESS failure branch, (d) PV cell failure branch.

The block diagram of the FTA of the whole system is split into four. However, PEMFC failure, ESS failure, and PV failure must connect the OR gate to the power source failure of the hybrid PCS. In the FTAs, the undeveloped event is assumed equal to the maximum basic event failure rate in the systems. Referring to MIL-HDBK-217F[3], the environmental factor chosen is G_F, which refers to installations in permanent racks with adequate cooling air and the possible maximum temperature that can occur around its value of 60°C. The results of each failure rate as shown in Table I, the MTTF value is equal to $1/\lambda_{total}$ = 4.2991 years and the reliability varies with the time domain as shown in Fig. 3.

Table 1 The results of each system failure rate value

Description	Symbol	Value	Unit
Hybrid PCS failure	λ_{total}	0.265533	failure/10^4hours
PEMFC failure	λ_{PEMFC}	0.063346	failure/10^4hours
ESS failure	λ_{ESS}	0.068405	failure/10^4hours
PV cell failure	λ_{PV}	0.036377	failure/10^4hours

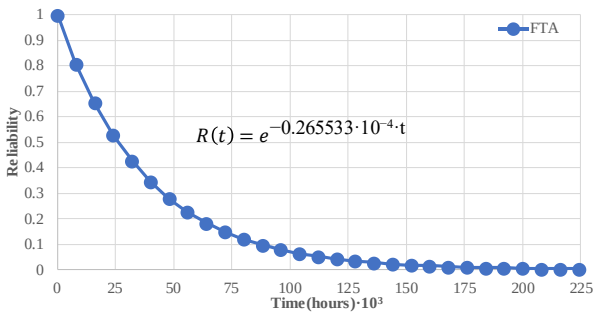

Fig.3 Evaluation of reliability of hybrid PCS

3. Conclusion

The failure rate of each component used is directly related to the reliability of the hybrid PCS. This analysis was demonstrated by considering the block structures of the FTA approach. As a result, it was observed that the reliability values decreased over time. The MTTF value is 4.2991 years, it can predict the average time between the start and the first failure of a non-repairable system and show us that the proposed idea's expected lifespan is long and highly efficient.

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