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AIR CONDITIONER RELIABILITY: REVIEWING PAST INSIGHTS AND FUTURE CHALLENGES

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Abstract

Reliability modeling of air conditioning (AC) systems is crucial for ensuring efficient performance, reducing maintenance costs, and enhancing system longevity. This paper presents a comprehensive literature review on the reliability analysis of air conditioning systems, focusing on various modeling techniques, failure patterns, and maintenance strategies. The study explores the application of probabilistic methods, including Markov processes, fault tree analysis (FTA), and failure mode and effect analysis (FMEA) to evaluate system reliability. The review highlights the importance of preventive and predictive maintenance in improving system reliability and minimizing downtime. Key challenges in reliability modeling, such as complex system configurations, multi-component dependencies, and real-world data limitations, are also discussed.

Keywords: Air Conditioner , Reliability , Operative

Introduction

Air conditioning (AC) systems play a vital role in maintaining comfortable and controlled indoor environments in residential, commercial, and industrial settings. The reliability of AC systems is critical to ensure consistent performance, energy efficiency, and user comfort. Failures in AC systems can lead to discomfort, increased energy costs, and damage to sensitive equipment.

Reliability modeling of air conditioning systems helps in analyzing the failure patterns, optimizing maintenance strategies, and improving system availability. This literature review explores key research contributions and methodologies in reliability modeling of AC systems, with a focus on two-unit redundant systems, repair strategies, and environmental factors affecting system performance.

Reliability Modeling in Air Conditioning Systems

Air conditioning systems are complex mechanical and electrical setups comprising compressors, condensers, evaporators, and control units. These systems are prone to failures

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due to mechanical wear, refrigerant leaks, electrical malfunctions, and environmental stressors.

Two-unit systems have been widely adopted in AC systems to provide redundancy and ensure continuous operation in case of primary unit failure. The standby unit can be in cold, warm, or hot standby mode depending on the operational requirements and switching strategies.

In 1996, Tizuka, Ishiyama, Hata, Sato, and Fujibayashi [1] have found several possible modification for lubricant and materials to maintain the reliability of compressors. In 2004, Myrefelt [2] studied the type of probability distribution for " Mean time to repair" , " Mean time between failures" and " Decision time " and shown that the log-normal type of distribution applies here. His study also gave interesting results about the status of the studied HAVC systems. In 2006 , Frenkel and Khvatskin [3] were suggested Markov rewards models for comparison analysis of two possible confriguarations of air conditioning systems. In 2016 , Pandey and Dwivedi [4] gave the different approaches for reliability calculation and hence it gives idea to select more easy method for calculating the reliability of a dynamic system. In 2018 , Sharma et al. [5] proposed a two-unit cold standby model for AC systems, analyzing system availability using Markov processes and steady-state analysis. Their study showed that repair rate and switching time significantly affect system reliability. In 2020 , Gupta and Mehta [6] introduced a dynamic switching model for multi-state AC systems, incorporating environmental factors such as temperature and humidity into the reliability analysis. Their findings indicated that adaptive switching based on environmental conditions enhances system performance. In 2021 , Patel and Kumar [7] proposed a hybrid cold-warm-hot standby model for AC systems, demonstrating that load sharing and priority-based repair improve system availability and reduce switching costs. In 2022 , Singh and Rao [8] analyzed the effect of imperfect switching on two-unit AC systems. Their study revealed that human error during switching increases system downtime and suggested developing fault-tolerant switching mechanisms. In 2022 , Kumar [9] focused on the study of impact of air conditioning on the environment and the different aspects that that should be known before installing air conditioning system. In 2022 , Alawadhi and Phelan [10] provides an overview of residential vapour-compression air conditioners operating under high ambient temperature (HAT). In 2022 , Pandey , Pandey and Saket [11] has shown that Solace cooling manages cooling of private structures , work places , vechiles , transports , trains and planes vets. In 2023 , Mishra et al. [12] introduced an AI-based predictive maintenance model for AC systems. Their model used machine learning to predict failures and optimize maintenance schedules, reducing operational costs and improving system reliability. In 2024 Kale , Shelar , Anti , Jale , Roy and Patil [13] analyze that the A/C evaporator and blower front sides were observed to be the most critical subsystems , contributing to approximately 50% of all failure. In 2024 , Benyanmine , Fezzioui , Ayad , Kaid , Benti , and Meeni [14] highlights the complex interplay between human behaviour , AC usage patterns , and indoor air quality , emphasizing the need for targeted interventions to promate responsible AC use . In 2024 Aswina , Sitania and Sukmona [15] has shown that it is necessary to plan a maintenance

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program for air conditioner facilities to maintain machine reliability and extend machine . In 2024 Xu , Wang , Zhou , Wu , Chen and Zhou [16] proposed a method for air conditioner reliability analysis combining Dynamic Bayesian Network (DBM) and Markov Model (MM).

Conclusion

Reliability modeling of air conditioning systems is essential to ensure consistent performance, reduce downtime, and optimize repair strategies. Advancements in dynamic switching, load sharing, and AI-based predictive maintenance have enhanced system reliability and reduced operational costs. However, challenges related to environmental stressors, switching delays, and human errors require further research. Future models should focus on integrating real-time monitoring and AI-driven optimization to enhance system performance.

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