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FUZZY-BASED RELIABILITY ASSESSMENT OF SOLAR PHOTOVOLTAIC SYSTEMS USING MODIFIED FMECA AND FAULT TREE ANALYSIS

[1]Preeti, [2]Dr. Harsh Vardhan

[1,2]Department of School of Statistics, Shri Venkateshwara University, Gajraula (Uttar Pradesh)

Corresponding Author:
preexisiting97@gmail.com

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ABSTRACT

Based on the current scenario, solar PV has a great opportunity to grow. Due to the installation of this system a operating and ecological problems may arise on a large scale. However, this kind of technology was very effected to reduce the greenhouse effect. These stresses have the potential to decrease the efficiency and availability of the system. While traditional FMECA offers a methodical way to rate parts that fail, it may provide the same Risk Priorities Numbers (RPNs) for various failure scenarios due to its dependence on clear numerical ratings. However reliable sources are always needed to grow up a complete system. Fault tree analysis (FTA) has the ability to identify the failure sources very quickly but these are no always accessible. In order to better prioritize failures in solar PV systems, this research looks at a comprehensive durability evaluation approach that combines improved FMECA with fuzzy-based FTA. On another way fuzzy and conventional methods are mostly evaluated the critically failure model. The fuzzy based model like FTA is mainly applied to cut set contribution system and identify the better one. The thesis-based findings identify fractured interconnections, bus failures and melted cables among the major component-level reliability concerns. The fuzzy FMECA approach provides improved differentiation between failure modes that may receive identical conventional RPN values. Furthermore, fuzzy FTA classifies 46% of minimal cut sets as very critical, 36% as moderately critical and 18% as less critical. Inverter failure, PV module output reduction due to soiling and shading, and surge protection device failure are identified as important contributors to system unreliability. In order to better prioritize maintenance and promote more educated quality administration of solar PV systems, the results show that fuzzy-based element evaluation and system-specific fault analysis may be combined.

KEYWORDS: *Solar Photovoltaic system, Fuzzy logic, FMECA, Fault tree analysis, RPN, Minimal Cut sets, Reliability assessment.*

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1. INTRODUCTION

In the current century, solar PV demand is continuously growing because of the best rapiod development and reducing greenhouse emission. When electricity comes from solar equipment, it has lots of benefits there like modular setup, flexibility, reliability. In a complete solar system model every component must be performed accurately as expected like cables, panels, batteries and safety devices.

In every condition like budget service Solar PV setup is perform better than the grid electricity but some conditions might affect this system like dust, shadow and solar irradiation. This can lead to cell cracking, hot spots, corrosion, connections being damaged and electrical insulation deterioration. A failing component could mean a loss in production, loss of power, and high cost of repairing the component. The reliability assessment process will be used to identify failure sources and develop efficient maintenance programs (Sussams and Leaton, 2017).

Traditional approaches, "such as Fault Tree Analysis (FTA), Analysis of Failure Modes and Effects (FMEA), and Failing Mode, Effects and Criteria Analysis (FMECA)" were mainly use when components are failed or a occur a glitch in the entire system. (Hamzeh, et al 2015). On the other hand, inadequate failure data and doubts in expert evaluations could restrict the use of traditional approaches. Specifically, for various failure modes, the RPN values may be the same since traditional FMECA uses ratings for severity, incidence, and detection to determine risk priority **(Adefarati, & Bansal, 2017).**

Fuzzy logic offers a different way to express judgments that aren't completely definite by using language parameters and membership functions. By combining it with FMECA and FTA, it may help evaluate potential failure paths at systems level and make failure priorities clearer **(Abunima, & Teh, 2020).**

The current work explores modified FMECA and fuzzy-based FTA for evaluating solar PV system dependability. It focuses on the detection of large failures of components, traditional and fuzzy prioritizing (assessment), and the minimum cut sets responsible for the loss of system or system level reliability.

A non-toxic energy outlet was crucial for our civilization as our energy consumption continued to rise. A lot of work has gone into bettering the sensitivity of solar PV and increasing the amount of energy that can be extracted from just one kind of solar energy panel today. Finding a systemic flaw or failure was defined in the earlier study using the technique of FMCS, FMEA, and FTA. **(Li, et al 2017; Syamsuddin, 2021)**

The ordinary FMECA methodology lays wildly different possible types of failure, their foundations, and the result of every single one. The Risk Preference Rank is often computed as:

$$\mathrm{RPN} = S \times O \times D$$

In the above formula S is denoted with severity, O denotes with the signified academic occurrence, and D was denoted with detectability. By contrast, in an attempt differentiate between the the different sets of scores, this system applied a rating algorithm. Thus, the maintenance priorities may not suitably capture the differences amongst the failure characteristics.

This shortcoming is circumvented by fuzzy-based dependability evaluation, which uses language variables to reflect ambiguous expert judgments. Triangular fuzzy numbers can be expressed as:

$$\tilde{A} = (a, b, c)$$

The number values of a, B, and C are the lowest point, creative medium,, and highest creative potential, respectively, in the preceding form of communication. To get relative risk priority, these fuzzy numbers may be run through the right reasoning and rating mechanism.

By looking at the possible outcomes of different component failures that might lead to a bad system incident, FTA offers an additional perspective. The identification of minimal cut sets helps determine the smallest combinations of basic events capable of initiating the top event. However, conventional FTA requires sufficiently accurate failure probabilities, which may be difficult to obtain for all PV components.

2. OBJECTIVE OF STUDY

This study uses FMECA and conventional methods to identify and priorities significant failure modes in PV systems. It also applies fuzzy risk assessment and conventional logic to determine critical minimal cut sets.

3. METHODOLOGY

The present work made use of the interdisciplinary research approach and presented the educational learning and comparative nature thesis assessment methodology.

3.1 FAILURE MODE IDENTIFICATION

In the very first step, you'll need to figure out what may go wrong with photovoltaic modules, wires, inverters, power sources, and safety gear. Module rusting, cell deformation, dust buildup, hot spots, broken connections, faulty bus breakdowns, and cable melting are some of the major failure modes that are considered.

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3.2 CONVENTIONAL FMECA

The assessment, degree of creativity, severity, and detection scores are the primary variables that determine how most errors are measured. The standard procedure may be used to get the creative NP by:

$$\text{RPN} = S \times O \times D$$

The outcomes are then applied to classify the unsuccessful modes in order of magnitude for maintenance activities.

3.3 FUZZY-BASED FMECA

In the way of installation of PV solar FMECA was used for language evaluation in the efforts of reducing uncertainties criterion. The force of gravity, rate of occurrence and identifying metrics are fuzzy membership procedures. However this technique was primarily used to deal with the ambiguous evaluations.

In broad terms, the uncertain risk factor may be expressed as:

$$\widetilde{RPN}_i = \tilde{S}_i \otimes \tilde{O}_i \otimes \tilde{D}_i$$

where the tilde indicates fuzzy quantities and $\otimes$ represents the adopted fuzzy multiplication operation.

3.4 FUZZY FAULT TREE ANALYSIS

The system-level investigation begins by defining the top event as the failure of the PV system to perform its intended electrical function.

Minimal cut sets are subsequently identified and ranked using the fuzzy-based evaluation procedure:

$$P(TE) = P\left(\bigcup_{j=1}^{m} MCS_j\right)$$

where MCS_j represents the individual minimal cut sets. It is necessary to use proper joint probabilistic connections to assess the likelihood of occurrences when they are interdependent or overlap.

3.5 COMPARATIVE ASSESSMENT

The conventional and fuzzy-based prioritisation outcomes are compared to identify differences in component failure rankings. The investigation examines the impact of critical minimal cut sets on reliable systems and also the distinctiveness feature of fuzzy assess in distinguishing between the failure sources with similar classic RPN.

4.RESULT AND ANALYSIS

4.1 IDENTIFICATION OF CRITICAL COMPONENT FAILURES

The thesis findings identify fractured interconnections, bus failures and melted cables as important failure mechanisms affecting PV system reliability. These failures may interrupt electrical continuity, increase resistance and reduce effective power generation.

The conventional FMECA results also indicate the importance of module corrosion, cell cracking and hot-spot formation. Inverters and batteries receive moderate priorities in the reported assessment, while other component failures receive comparatively lower rankings.

4.2 COMPARISON OF CONVENTIONAL AND FUZZY FMECA

The evaluation demonstrate an essential advantage of fuzzy based system. Even if types of failure vary in severity, frequency, or detection features, traditional RPN computations may nonetheless give them the same numbers.

The thesis reports that fuzzy-integrated FMECA addresses this limitation by providing greater differentiation between failure modes. This improves the interpretation of criticality and provides a more informative basis for maintenance prioritization.

4.3 FUZZY FAULT TREE ANALYSIS RESULTS

The fuzzy-based FTA findings classify the identified minimal cut sets into three criticality categories.

Criticality category	Percentage
Very critical	46%
Moderately critical	36%
Less critical	18%
Total	100%

The results indicate that nearly half of the identified minimal cut sets belong to the very critical category. This demonstrates the importance of examining combinations of component failures rather than focusing exclusively on individual defects.

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The thesis particularly identifies inverter failure (MCS7), reduced PV module output due to soiling (MCS21), reduced output due to shading (MCS22) and surge protection device failure (MCS8) as important contributors to overall reliability degradation.

4.4 RELIABILITY AND MAINTENANCE IMPLICATIONS

The findings indicate that preventive maintenance should prioritise electrical interconnections, cable integrity, inverter performance and protective devices. Regular inspection of PV modules is also important for detecting corrosion, hot spots, soiling and shading-related performance losses.

The integration of fuzzy FMECA and FTA provides a more comprehensive assessment because it combines component-level failure ranking with system-level failure pathway identification. Care managers may use this information to focus examination efforts on parts and failure scenarios with the highest reliability impact.

5. CONCLUSION

In this investigation, a technique connecting fuzzy logic and upgraded FMECA using Problem Graph Analysis (PGA) has been utilized to gauge reliability of conventional solar energy arrangements. The investigation tackles problems inherent to traditional RPN calculations and the dependency on basic-event failure probability of the traditional FTA.

By analyzing the result, it has been concluded that failure at the component level is most dangerous for the entire system. Fuzzy-Integrated FMECA can be used to differentiate the failure priorities when RPN is identical in traditional evaluation. In addition, fuzzy-FTA results show that 46% of the minimum cut sets are very important, 36% somewhat critical and 18% are less essential. Inverter disappointment, soiling and shading, and surge traumatic problem/illustrations are all key elements in deconstruction system-level dependability.

As per the findings, integrative fuzzy unreliability evaluation may assist in enhancing failure being identified, criticality assessments, and proactive repair management. Nevertheless, the findings are encompassed only by the system setup, evaluation presumptions, and failure details provided in the thesis. Expanded operation datasets, failure reports from the field, and comparative dependability simulations should all be used to verify the framework in future study.

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