Implementation of Qualitative FMEA to Improve the Reliability of Space Transmitter Power supply

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Abstract - This paper presents a use of qualitative for failure modes and effects analysis (FMEA) in reliability calculation of power supply for space application. The presence of qualitative scales is mainly useful when quantitative data for estimation of probabilities are deficient and experts are averse to express their opinions quantitatively. Such causes are often not computable due to proto type is not ready. This paper describes the proposed structure and demonstrates its uses through a simple example [1].

In this paper, qualitative method FMEA for designing a satellite power supply has been implemented and it has been shown that this analysis serves as a useful tool to identify critical items of the product, which leads to consider modifications for preventing failures and finally improving system reliability. The overall activities, which have been done using FMEA technique with regard to cost, practical restrictions, and system technical hitches, lead to an improvement in reliability.

Index Terms - EPC; FMECA; Failure rate; Criticality analysis.

I. INTRODUCTION TO FMEA & SYSTEM

Reliability allied with a power supply is a measure of the overall ability of the power delivery system to fulfill the customer demand for electrical energy. In the past decades, several methods for assessing the distribution system reliability have been developed. These methods can be roughly categorized as the simulation and analytical methods. Analytical techniques [2] represent the system by mathematical models and evaluate the reliability indices from these models using mathematical solutions. The most widely used analytical techniques include:
FMEA Technique,
State Space Analysis [4, 5],
Network reduction etc. [4, 5].

The FMEA technique identifies all the possible failures modes, on a component-by-component basis and their resulting effects on the system. In State Space Analysis, also known as Markov modeling method, the entire system is divided into zones and branches and the zone reliability indices are applied to all the branches in the zone. In the network, reduction method the network is divided into sub-networks which are series and parallel combinations and then estimate the indices. In this paper reliability parameters are evaluated for power supply for satellite transmitter using FMEA technique.

The Electronic Power Conditioner (EPC) incorporates multiple DC-DC converters configured for powering various electrodes of a TWT, with built-in sequencing, fault monitoring and protection mechanisms besides a command interface module.). Power supply transforms the 270VDC input to 4300V, 5V and 15V DC to caters power for TWT and all devices of EPC. The EPC is designed to work with a micro-TWT for configuring a MPM. The components are high voltage ceramic capacitors with low ESR, thin-film capacitors, electrolytic Capacitors, variable resistors, precision resistors, diodes, Transient Voltage Suppressor(TVS), surge suppressor,crystal,micro-controller and resistors.

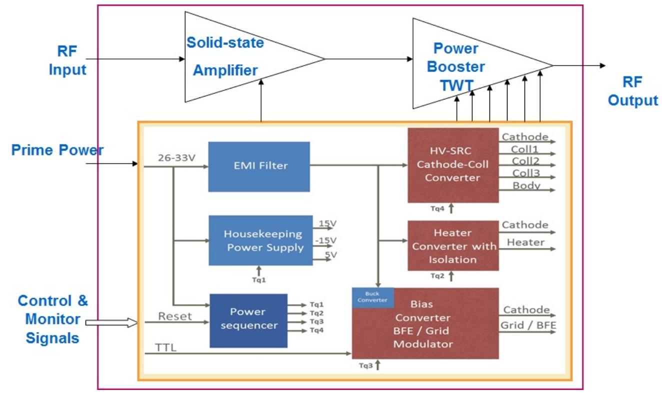

Fig.1 MPM Block Schematic

II. EPC MODULE

II. APPLICATION OF FMEA TO POWER SUPPLY

FMEA is an approach, which systematically details, on a component-by-component basis, all probable failure modes identifies their resulting effects on the system. Probable failure events of each component in the system are identified and evaluated to determine the effects on the load points. In the analysis, a test system defined as Roy Billinton Test System.

As mentioned, FMEA is an analytical tool to provide a systematic and dynamic method for prioritizing failure modes based on a quantitative factor. In this way, all potential failures in a system design with specified instructions have been recorded, and the effect of each failure on system performance is determined. Then the failures, which are critical for the success of the mission, are specified and ranked according to their severity. Finally, valuable information for other reliability programs is provided. The ranking is used to determine critical failures or risks, which should be eliminated or mitigated. The FMEA process is a bottom-up approach to system analysis. In other words, it analyses the system from the lowest level of the components and determines which components may fail, how and why they fail and what the effects of these failures on the system are. If the analysis is extended to quantify the severity and probability of failures (or failure rate) of the equipment, further parameters such as criticality number are added to the FMEA worksheet so we would have failure modes and effects criticality analysis (FMECA) [3]. In general, the steps to conduct a FMEA are as follows:

- Developing a block diagram
- Entry potential/actual failures and product function
- Classification of the failures and evaluating their severity level
- Determining the effects of failures on product
- Initial valuation of Risk Priority Number (RPN)
- Reevaluation of the RPN after actions are completed to mention that design controls are

1) Preventive controls which include the ones prevent occurrence of failure cause, and
2) Detection, which include detection of failure mode, mechanism/cause of failure occurrence, and the actions that must be done.

III. IMPLEMENTATION PROCEDURE

A detailed functional FMEA analysis has been conducted on EPC. The EPC being a mission critical device, to be produced for defense applications, the safety is of a greater concern, which makes any failure that falls under catastrophic/critical severity level, whether or not it has a higher Total RPN, a problem, which needs to be taken care of.

The severity levels and their description have been decided and defined in consultation with MTRDC are as provided in Table 1. As mentioned in the FMEA algorithm, it is necessary to identify failure modes for each of the components after developing the block diagram of the product. The statistics of failure modes can be achieved from different units such as design, manufacture and assembly with using references of similar experiences [8] [9].

The functionality of each cards and its failure modes and next higher level and end effects on EPC are studied. The RPN Numbers are calculated for each failure mode of a particular card, which falls under specific severity classification.

Towards completing this analysis, detailed FMEA sheets have been prepared, a sample of which is provided in Table 2.

S. No	Severity Category	Description	RPN Range	Severity
1	Minor	Minor or negligible effect on functionality	< 6	I
2	Major	Leading to failure in long run. Functionality deviation within acceptable limits	6 <12	II
3	Critical	Certain or leading to functional failure. Failure of important protection. Requires immediate attention.	12 to <18	III
4	Catastrophic	Imminent damage to EPC. Total mission loss. Costly failure (damage to TWT, SSPA etc.). Failure of vital protection	18 to < 27	IV

Table 1 EPC severity level description

Card	Function	Failure Mode	Failure Cause	Next Higher Assembly Effect	OxSxD	Failure Effect	Severity Order	RPN
Control & Logic Card	Detection of the various faults that may occur in a transmitter and transfer fault status to Digital interface board. Maintains proper switching ON/OFF sequence for safe operation.	Functional Failure (input threshold voltage, timing, output voltage)	Use of unscreened components/ Over heat	No communication signal to assemblies	3x3x2	No input to beam focusing electrode	IV	18
		Short circuit between any two connections	Improper Soldering	No enable signal for SSPA and HSK	2x3x 1	No supply to SSPA and HSK	II	6
		Open circuit of any connection	Improper Soldering	No enable signal for SSPA and HSK	2x3x1	No supply to SSPA and HSK	II	6
		Parasitic oscillations of outputs	EMI effect	Negligible variation from desired output	3x2x3	Negligible variation from desired output	III	18
		Open circuit of any Bypass capacitor connection	Thermal Issue	Minor variation in output	1x1x2	Negligible variation from desired output	I	2

Table 2 FMEA sheet of control & logic card

IV. CRITICAL ITEMS LIST

Critical cards can be identified based on criticality number (CN) as a result of multiplying severity number and occurrence likelihood number for each failure mode. So one part of a product is called critical if its failure mode has a catastrophic consequence (severity number = 4) or its criticality number is bigger than or equal to six. Hence, critical items list for payload has been shown due to Table 3. This list allows the items to receive special attention in development, manufacture, installation, and test.

(a) The criticality matrices have been prepared using the RPN. The System Level Criticality Matrix of EPC is shown in Fig 2.

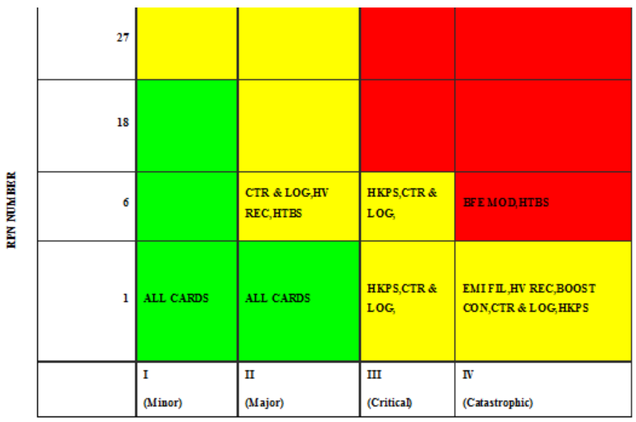

Fig. 2: Criticality Matrix of EPC

(b) Card-wise corrective action priorities may be decided based on the components and the region in which they fall (RED, YELLOW or GREEN). Here RED region depicts the immediate priority of corrective action at the card level, as failures in this region are potentially high-risk failures leading to catastrophic/critical effect on system operation or personnel safety. In addition, improvements in these components will yield significant reliability improvement through increased component quality, derating or redundancy implementation. YELLOW and GREEN region marks the successive priority levels.

There are various failure modes in a single card, which would lead to different level of severity effects at the EPC level. However, some failure modes in different cards would be leading to same effect of same severity class, again at the EPC level. For instance, control logic and fault detection, heater and bias supply have certain failure modes, which are leading to the effect ‘No control on cathode voltage’ with a severity of “Critical’.

V. CONCLUSION

From the analysis of the assembly level severity level, it can be observed that heater and bias supply and BFE modulator are the most critical since it is the only card with resulting failure effects falling in the RED region. This suggests that this card should be given the highest priority in any correction or design change to bring it outside the red zone through the reduction of it RPN either by reducing it severity/occurrence or by increasing the detectability for such malfunctioning, and subsequently the rest of the cards can be prioritized by the region in which they fall, with YELLOW and GREEN regions in decreasing order of priority.

VI. ACKNOWLEDGMENT

The authors are thankful to Director, MTRDC for permitting to publish this work and all MTRDC officers, supporting staff for their contributions to complete the above activities.

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