AHP Based Evaluation Method for Technology Readiness Level of DC-DC Converter

*Jiaoying Huang**
School of Reliability and System Engineering
Beihang University
Beijing, China
huangjy@buaa.edu.cn

*Xubo Lv**
School of Reliability and System Engineering
Beihang University
Beijing, China
lv_xubo@163.com

*Cheng Gao**
School of Reliability and System Engineering
Beihang University
Beijing, China
gaocheng@buaa.edu.cn

***Abstract*—DC-DC converter is an electronic circuit that converts a source of direct current (DC) from one voltage level to another. It's widely used because of its short design period and high reliability. It is very important to evaluate technology readiness level (TRL) of DC-DC converter accurately. In this paper, Analytic hierarchy process（AHP） based evaluation method is proposed to calculate TRL value of DC-DC converter. A hierarchy model of objective remaining to be evaluated needs to be developed in the beginning. The structure of model is divided into three layers respectively called objective layer, criteria layer and alterative layer. Objective layer consists of the device itself and comprises several criterions such as technology, material, design and manufacturing. The third layer includes all concerning specific elements. Then, assign weight value for each criterion and construct normalized pairwise comparison matrix. Maximum eigenvalue and corresponding eigenvector is calculated by mathematical method for further consistency examination, which ensures the reliability of decision maker. Finally, TRL of the device can be calculated as 0.93 according to known TRL value of each element of it. The result shows that TRL of DC-DC converter is more than 0.9, which means it is in the condition of high maturity and is suitable for large-scale application.**

Keywords—DC-DC converter, TRL; Analytic hierarchy process; pairwise comparison matrix; consistency

I. INTRODUCTION

DC-DC converter is a highly-integrated complex electronic system contained with large number of electronic components including integrated circuits, resistors, capacitors, transformers and inductors [1,2]. Its performance is directly affected by technology readiness level (TRL) of design technology, packaging crafts, materials and components during its production processes.

Reliability of DC-DC converter is mainly influenced by application condition and environment [3]. In general, the reasons that caused early failure of DC-DC converter mainly consist of potential internal sub-circuit defect, incomplete assembly or inappropriate operating behaviors. Inherent failure life is determined by a few factors such as occasional over-stress, inadequate design margin and lower cycle fatigue stress. There are some other failure modes such as aging and degeneration of electronic components or fatigue of interconnection and solder joint.

TRL is an assessment for evaluating technology level of DC-DC converter [4,5]. TRL means the maturity of technology development. It indicates the level that technology has reached to the extent of general availability in development process. It is helpful for enterprise to standardize processes of product design and manufacturing and to reduce risk of failure by accurate evaluation of TRL [6]. As a result, method is required to evaluate TRL of DC-DC converter comprehensively.

Key process areas (KPA) and Analytic hierarchy process (AHP) are two of effective methods that is used to evaluate TRL.

KPA comes from capability maturity assessment framework which is developed by Carnegie Mellon University for evaluating software capability maturity [7]. In practice, goals that needed to reach certain technology readiness level should be set when the level is determined. KPA is the combination of these goals. KPA is a qualitative approach which is simple and easy to operate [8]. However, as a qualitative approach, the evaluation results often have poor accuracy and its quality is totally determined by the goals.

AHP is a decision-making method which break the elements associated with final decision into different layers such as objective layer, criteria layer and alternative layer. Systematic analysis then is carried out using mathematical methods on analytic hierarchy [9,10,11]. AHP is a systematic method that combine qualitative and quantitative means which is simple and practical to make decisions, and does not require too much quantitative data. But AHP can only extract program from the original programs and can't create new program for decision-maker.

The key elements of DC-DC converter consist of material elements, craft elements and design elements in addition to technology elements. Multiple types of elements have multiple affects on TRL of DC-DC converter. However, the previous studies are mainly focused on systematical level, only considering new technology elements that share same properties and it's no longer applicable on DC-DC condition. Since AHP has better characteristics when dealing with the condition that objective is affected by multiple technical elements, we firstly applied AHP based method in the evaluation of DC-DC converters' TRL quantitatively and significative results were obtained.

II. AHP BASED EVALUATION METHOD FOR TRL

Triggered by the resource allocation and planning problem in defense industry, AHP was introduced firstly to the literature in 1971 by T.L.Saaty. Up to now it is one of the most frequently used Multiple Criteria Decision Making Techniques. AHP was used in different areas like politics, economics, social and management sciences to solve unstructured problems [12].

AHP gives the opportunity to model complex problems with its main target, criteria, sub-criteria and decision alternatives, in a hierarchical relation network. Giving decision makers the chance of including both objective and subjective decisions in decision making process is the most significant feature of AHP. The method is generally used for complex, ambiguous and unstructured problems, and based on three principles [13].

- Construction of hierarchies
- Definition of priorities
- Logical and numerical consistency

A. Define decision elements under the hierarchical structure (criteria, sub-criteria, alternatives)

Construct hierarchical structure with associated decision elements from top to down according to different properties. The elements in same layer are subordinate to upper layer and dominate the elements in next layer. Objective is usually regarded as uppermost layer, usually consists of one element. The lowermost layer is generally alternative layer. In the middle are criteria layer. The objective layer can be usually the object remaining to be analyzed while criteria layer consists of multiple elements of the object and alternative layer includes TRL of each element.

B. Make pairwise comparisons between decision elements and obtain comparison matrices

For every decision elements a_{ij}, indicates the extent of affect that the i_{th} element makes to objective compared to that of j_{th}. Then quantize the extent according to table 1.

The comparison matrices:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

$$a_{ij} > 0 \text{ , } a_{ij} = 1(i = j) \text{ , } a_{ij} = \frac{1}{a_{ji}}$$

TABLE 1 DESCRIPTION AND QUANTIZATION PRINCIPLE

a_{ij}	**Extent of impact** (Compare i_{th} with j_{th})
1	Equivalent
2	Between the same and slightly stronger
3	Slightly stronger
4	Between slightly stronger and stronger
5	Stronger
6	Between strong and much stronger
7	Much stronger
8	Between much strong and extreme strong
9	Extreme strong

C. Calculate the relative weights of decision elements by using eigenvalue method.

Define Weight vector calculation methods in AHP include geometric mean method and arithmetic mean method.

For geometric mean:

$$U_k = \sqrt[n]{\prod_{j=1}^{n} a_{kj}}$$

$$U = (U_1, U_2, \dots, U_n)^z$$

For arithmetic mean:

$$U_k = \frac{\sum_{j=1}^{n} a_{kj}}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}}$$

$$U = (U_1, U_2, \dots, U_n)^z$$

Maximum corresponding eigenvalue according to weight vector can be calculated.

$$\lambda = \frac{1}{n} \sum_{i=1}^{n} \frac{(AU)_i}{u_i}$$

D. Calculate the consistency of matrices in order to ensure the reliability of decision makers.

Define consistency index of pairwise matrices

$$CI = \frac{\lambda - n}{n-1}$$

which n represents the sum of diagonal elements of A.

Define random consistency index RI values as shown in table 2.

Define consistency ratio

$$CR = \frac{CI}{RI}$$

When CR < 0.1, the inconsistency of A meets the requirement. Normalized eigenvector of A can be regarded as weight vectors. When CR > 0.1, the pairwise comparison matrix A needed to be adjusted until A meets the CR requirement.

TABLE 2 RANDOM CONSISTENCY INDEX RI

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

E. By combining relative weights of decision elements, calculate the total score for each alternative.

Assuming that TRL of objective is , TRL of every elements are, then:

$$T_0 = U_1T_1 + U_2T_2 + ... + U_nT_n$$

III. CASE STUDY

In this paper, AHP is applied to DC-DC converter HTW28S05 (The device) to evaluate its TRL.

Firstly, construct hierarchical structure of DC-DC converter (goal, criteria, sub-criteria, alternatives). Then, calculate the weight vectors based on hierarchical structure. Finally, calculate TRL of goal combined with TRL of every element.

A. Define decision elements under the hierarchical structure of DC-DC converter

In the evaluation for TRL of DC-DC converter, comprehensive TRL of DC-DC converter should be considered as objective layer. Criteria layer consists of five criteria: technology criteria, material criteria, design criteria, manufacturing criteria and certification criteria. Alternative layer comprises several key elements in every aspect of DC-DC converter. The determination of key elements is due to conventional AHP questionnaire (nine points scale pairwise comparisons) that is distributed to number of experts in this field.

In Figure1, the structure of AHP model on DC-DC converter is given

B. Make pairwise comparisons between decision elements and obtain comparison matrices

Make pairwise comparison between first four elements and the comparison result are shown at table 3.

Pairwise comparison matrices were generated by table 3.

$$A_{ij} = (a_{ij})_{4\times4} = \begin{bmatrix} 1 & 1/4 & 1/3 & 1/4 \\ 4 & 1 & 2 & 2 \\ 3 & 1/2 & 1 & 1 \\ 4 & 1/2 & 1 & 1 \end{bmatrix}$$

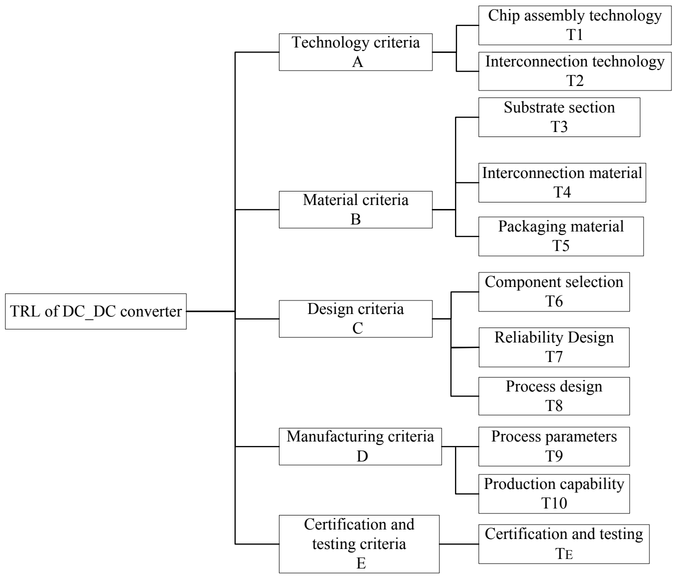

Fig. 1. Hierarchical structure for TRL of DC-DC converter

TABLE 3 PAIRWISE COMPARISON RESULTS

Pairwise comparison between first four elements	**Element that is more important**	**Extent of importance**
Technology VS material	material	4
Technology VS design	design	3
Technology VS manufacturing	manufacturing	4
material VS design	material	2
material VS manufacturing	material	2
design VS manufacturing	equivalent	1

C. Calculate the relative weights of decision elements

Figure Arithmetic mean method was used to calculate weight vector:

$$U_k = \frac{\sum_{j=1}^{n} a_{kj}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}}$$

$$U = (U_1, U_2, ..., U_n)^z$$

Then

$$U = (U_1, U_2, ..., U_n)^z = (0.0825, 0.4274, 0.2346, 0.2554)$$

Where a_{ij} is in A as above.

D. Calculate consistency

It is calculated that the maximum eigenvalue λ corresponding with

$$\lambda = 4.166$$

Then

$$CI = \frac{4.166 - 4}{4 - 1} = 0.033$$

There are four criteria in this application so that

$$RI = 0.90\ ,\ CR = 0.037 < 0.1$$

A is consistent. Move to step 5

E. Calculate TRL of DC-DC converter by combining relative weights of each decision elements.

The TRL of each element from T1 to T10 are shown in Figure 2.

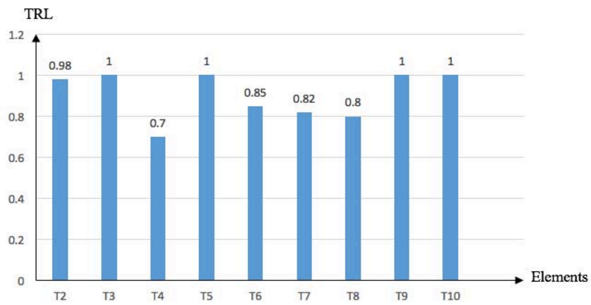

Fig. 2. TRL of each element between T1 to T10

The total TRL of DC-DC converter is calculated as follows:

$$T_0 = \frac{U_A}{2}(T_1 + T_2) + \frac{U_B}{3}(T_3 + T_4 + T_5) + \frac{U_C}{3}(T_6 + T_7 + T_8) + \frac{U_D}{2}(T_9 + T_{10})$$

$$T_0 = 0.93$$

The device is in Qualified Products List (QPL) which means $T_E = 1$ and has no effect on final T_0. Therefore, TRL of the device is 0.93 based on AHP model.

The result shows that TRL of DC-DC converter T is more than 0.9, which indicates that DC-DC converter has high reliability in application with low risk. Meanwhile, it is believed that technology and material elements have been mature while crafts and design of circuit have been verified as well.

IV. CONCLUSION

In this study, we proposed an evaluation method for TRL of DC-DC converter and made verification on a specific type "HTW28S05". To start with, a hierarchical structure of DC-DC converter with three hierarchies (objective, criteria and alternative) has been build. Then pairwise comparison matrices is required to generated based on relatively extent of importance between each elements retrieved by conventional AHP questionnaire from experts. Based on the pairwise comparison matrices, weight vector can be calculated as eigenvector to test consistency of matrices in order to make sure that the reliability of decision makers is within acceptable limits. Finally, the comprehensive TRL of objective is obtained by combining TRL of each element. Final result indicates that technology readiness of DC-DC converter "HTW28S05" has reached the level of large-scale application.

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