Design for Six Sigma (DMADV) Methodology for Power Inverter Development

Hussein Salem Ketan
Prof
Karrar Mahdi Husain
EngineeringCollege
Baghdad University\Iraq

Abstract

This research highlights the importance and the role of Quality Function Deployment (QFD) in determining the critical customer requirements in developing the Power Inverter pure sine wave (1 KVA) product produced by the Electrical Industries Company (EIC). Define Measure Analyze Design Verify (DMADV) methodology, which is one of the Design for Six Sigma (DFSS) methodologies was applied taking the first two phases as a part I, in phase one (Define) applying Affinity Diagram (KJ Analysis) and Kano Model tools to consist a powerful information base through brainstorming. In phase two (Measure) Voice of Customer (VOC) captured by Questionnaire form and applying Quality Function Deployment (QFD) tool in determining the Relative Importance (RI) for the Technical Requirements (TR) so that to choose the first three having the highest (RI) number which consider the Critical Customer Requirements (CCR) these are for power inverter product (Type of MOSFET "Metal-Oxide Semiconductor Field-Effect Transistor", Transformer design, cooling system).

Key words: DFSS, power inverter, Affinity diagram (KJ Analysis), Kano Model, QFD (House of Quality HOQ).

1-Introduction

In today's competitive environment, the companies that succeed will be those which develop products that satisfy customer needs better than the products of their competitors. Therefore, it is necessary that companies fully research such needs, and generate ideas and solutions that can best satisfy them [5]. Every product is sold in market for a price. For god products the customers are willing to pay higher prices [16]. Six Sigma provides specific methods to re-create the process so that defects and errors never arise in the first place [7]. The central idea of Six Sigma management is that if you can measure the defects in a process, you can systematically figure out ways to eliminate them, to approach a quality level of zero defects [2]. Statistically, Six Sigma refers to a progression in which the series between the mean of a method of excellence measurement and the adjacent specification edge is at least six times the standard deviation of the process [14.[

As defined by Creveling, Design for Six Sigma (DFSS) is a proactive approach to building the Six Sigma performance into the upfront design of a new product, service or process. It is a systematic methodology for designing new Six Sigma quality products to exceed customer expectations through the use of engineering tools and training in the product development life cycle [10 .[

A continuous improvement of the existing processes (DMAIC) and new developments (DMADV) represent linchpins of the Six Sigma methodology. Classic six sigma DMAIC (Define, Measure, Analyze, Improve, Control) – the improving process consists of five diffused and interacted stages resulting in stepped improvements of existing processes. Similarly the process designing new processes and products consists of five stages (Define, Measure, Analyze, Design, and Verify). The DMADV process as a DFSS methodology is principally used in situations where improving of the existing processes is no longer adequate owing to feasibility and cost-effectiveness [8]. In this work the Quality Function Deployment (QFD) is implemented with some DFSS important tools to determine the critical customer requirements in developing the Power Inverter pure sine wave (1 KVA) product produced by the Electrical Industries Company (EIC)

2- Design for Six Sigma (DFSS)

DFSS is a disciplined and rigorous approach to service, process, and product design through ensuring that new designs meet customer requirements prior to launch [4]. Adopting DFSS approach considered a powerful source to the company increasing its profits where proven practically that increasing Quality lowering cost through reducing waste and high competition by achieving customer requirements and with the highest sales ratios inventories reduces. Figure (1) explains how DFSS can lower production cost through dealing with defects in the design stage.

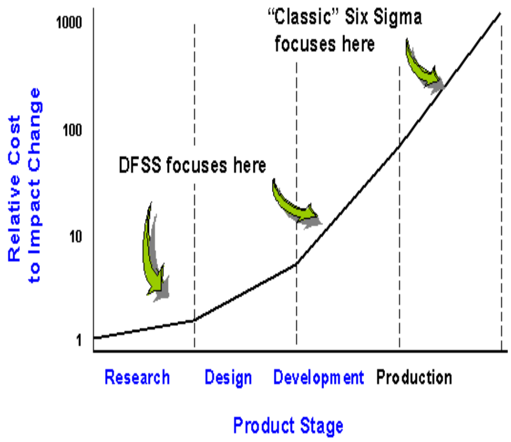


Figure (1): Cost analysis when applying DFSS [9].

3- Power Inverter

Power inverter is a device that converts electrical power from DC form to AC form using electronic circuits typically; it is possible to convert battery voltage into conventional household AC voltage allowing you to use electronic devices when an AC power is not available. There are basically three kinds of Inverter out of which, the first set of inverters made, which are now obsolete, produced a Square Wave signal at the output [3].

The Modified Square Wave also known as the Modified Sine Wave Inverter produces square waves with some dead spots between positive and negative half-cycles at the output. The cleanest Utility supply like Power source is provided by Pure Sine Wave inverters. The present Inverter market is going through a shift from traditional Modified Sine Wave Inverter to Pure Sine Wave inverters because of the benefits that these inverters offer these types explained in figure (2)[3].

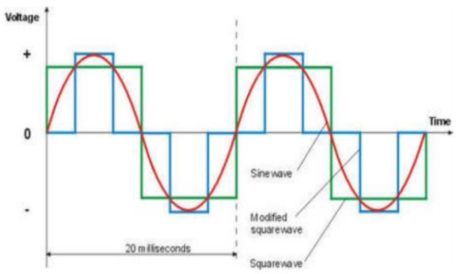


Figure (2): types of inverter outputs [3].

4- DFSS methodologies

DFSS has a various methodologies used to design or redesign products, processes or services as shown in figure (3) below:

The first one DMADV is a common methodology which is beneficial to improve products through its precise procedure that provide a rich set of tools to achieve project goals.

DFSS-Cycle	Hits of Google*	Phases					
DMADV	59.000	Define	Measure	Analyse	Design		Verify
IDOV	13.400		Identify		Design	Optimize	Verify
DMADOV	3.060	Define	Measure	Analyse	Design	Optimize	Verify
DMEDI	2.680	Define	Measure	Explore	Develop	Implement	
CDOV	1.730			Concept	Design	Optimize	Verify
DCCDI	1.350	Define	Customer	Concept	Design	Implement	
DCOV	1.350	Define		Characterize		Optimize	Verify
DIDOV	473	Define	Identify		Design	Optimize	Verify
DMADIC	76	Define	Measure	Analyse	Design	Implement	Control
DMCDOV	38	Define	Measure	Characterize	Design	Optimize	Verify

Figure 3:various DFSS methodologies [10]

.5 DMADV methodology and Implementation

The application of DMADV is used when a client or customer requires product improvement,adjustment,or the creation of an entirely new product or service. The application of these methods is aimed at creating a high-quality product keeping in mind customer requirements at every stage of the production[15] Figure (4) below show the flow chart of DMADV methodology used in this research to develop the power inverter pure sine wave(1 KVA)produced by(EIC)to make it more competitive in the inverters market through achieving lower cost with high customer satisfaction by using some important development tools which are varies from phase to another but they are a complement each other in the same time

.

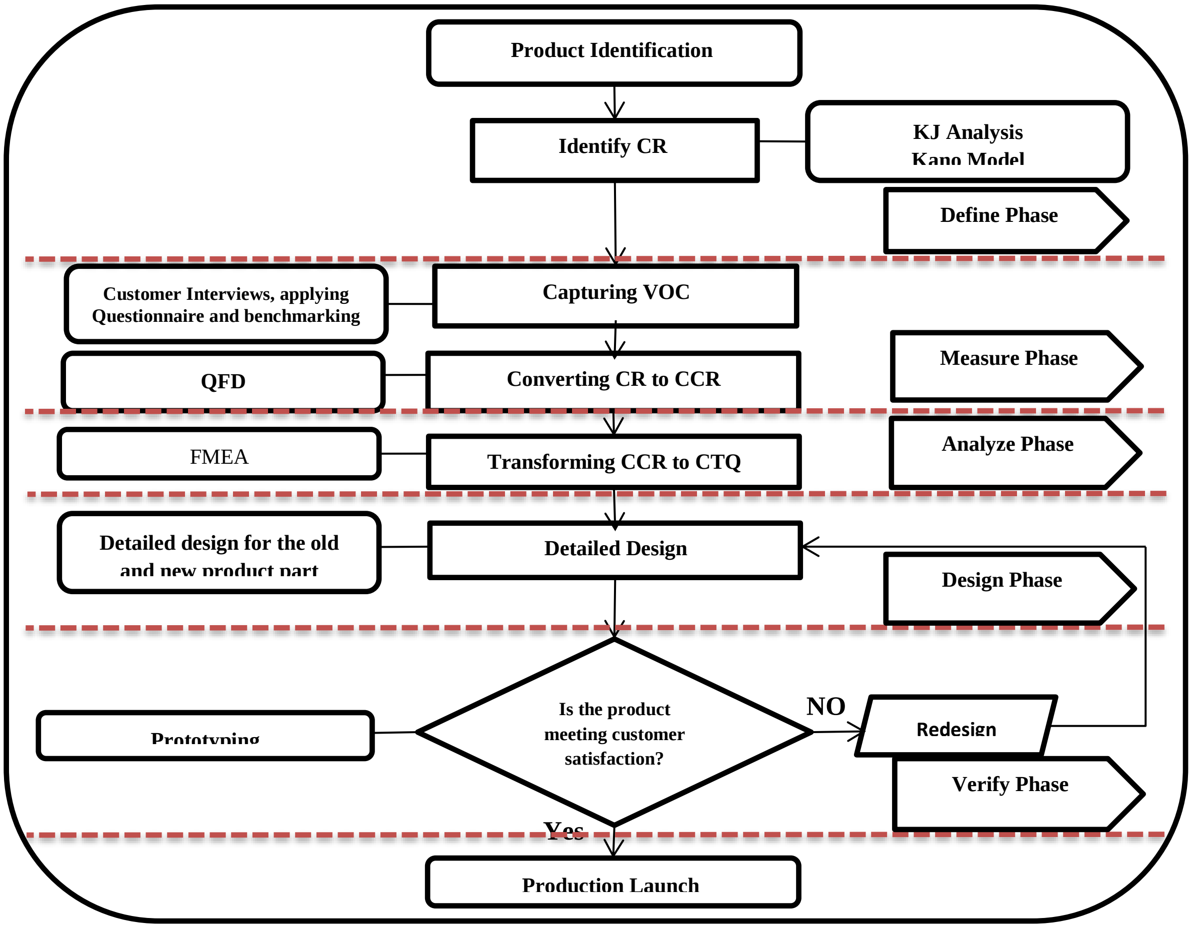


Figure (4): DMADV methodology flow chart

1.1 Define phase

Implementation of the quality improvement model begins with the Define phase. In the beginning of work on the project of quality improvement, the responsibilities have been identified, as well as the approach to the problem and the steps in solving the problem. It is imperative to immediately begin to define the scope of the project and to distinguish and exact define the variables that will be deal with [11].

1.1.1. Affinity diagrams (KJ Analysis):

It is a structured method to discuss, analyze and have a coherent vision of a complex and hard to define problem. The problem under study must be well defined and reported, and this is written on the top left of the board [1].

The main steps:

Idea generation: list of ideas resulting from brainstorming must written on a sticker paper that placed on a white board or wall randomly.

Grouping the ideas: here grouping similar ideas together in groups with a quiet and accurate work.

Create Affinity cards: also called header cards it is a fundamental idea placed on the top of every group, here alternative or supper header "relation between two or more groups" cards can be prepared also.

Finalize the Affinity diagram: putting the problem statement on the top and the header, alternative header and supper header cards above every group then connecting lines between the header and all the ideas in a hierarchical way which gives well analysis for the problem. Figure (5) shows the Affinity diagram for the power inverter development.

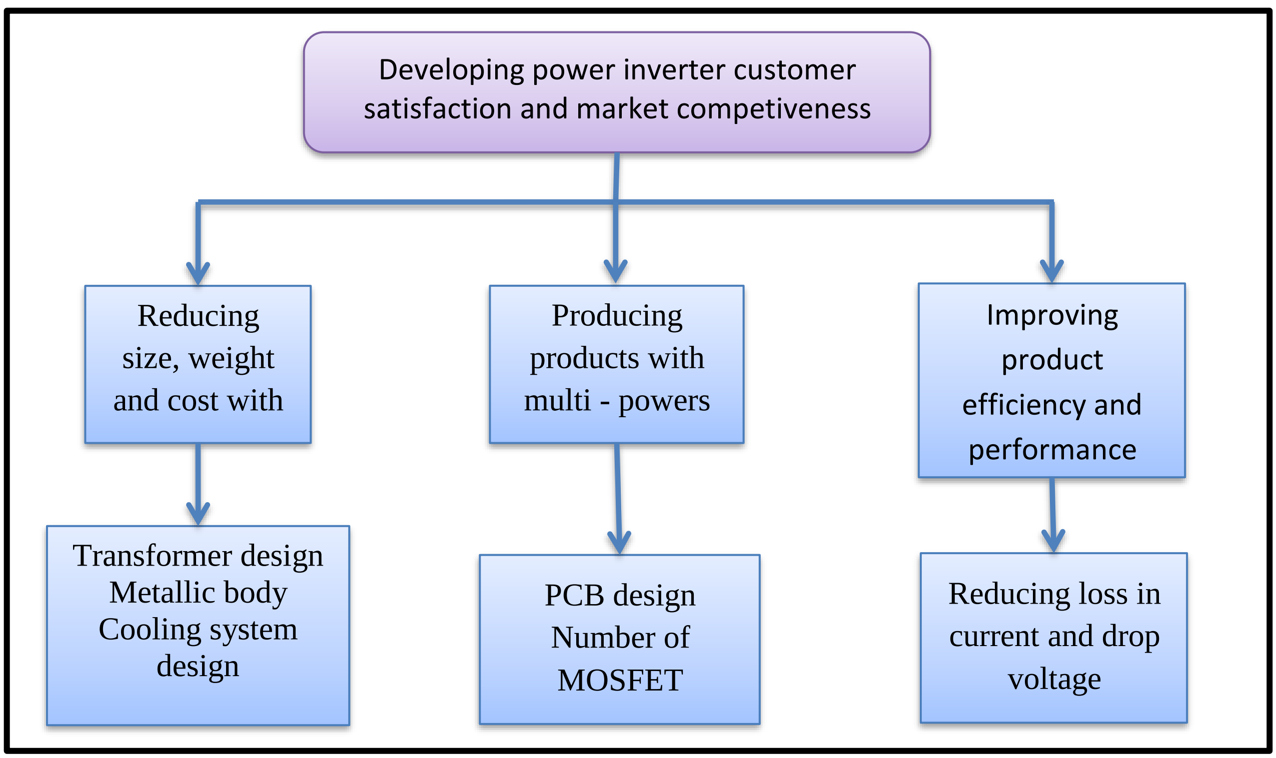


Figure (5): Affinity Diagram (KJ Analysis).

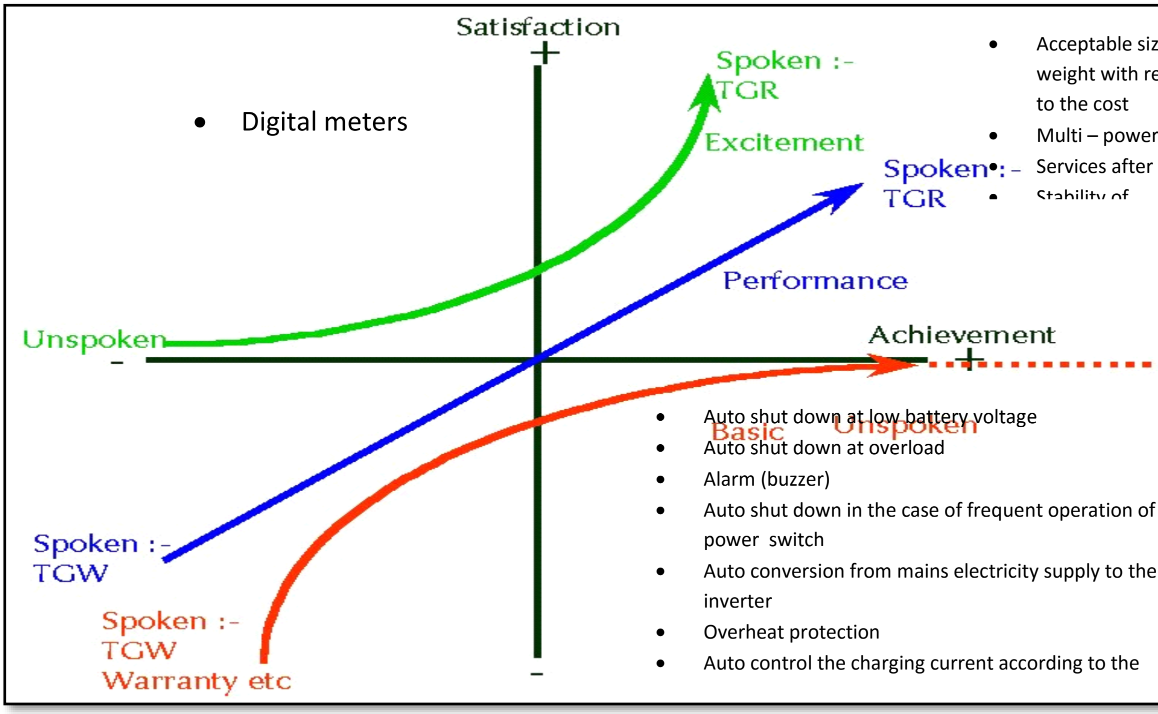


Figure (6): The Kano Model for Power Inverter Development

1.1.2. Kano Model:

The Kano model was developed in 1984 by Noriaki Kano [5]. It aims to connect the requirements fulfilled by products or services with customer satisfaction and identifies three types of requirements that influence ultimate customer satisfaction [13]. These types represented on the form shown in figure (6) for power inverter development which describe all the specifications needed to develop the product:

Basic characteristics (Must –be): it is the not spoken needs that already must be available in the product at least to achieve.

Performance needs: it is the spoken needs by the customer that affect customer satisfaction, as the level of the product performance within this area is high it will be accepted by the customer.

Excitement characteristics (Delighting the customer): it is also not spoken needs but in the positive side can be called Wow the customer the product within this area have a very customer satisfaction and market competition.

TGR (Things Gone Right)

TGW (Things Gone Wrong)

1.2.Measure phase

In this phase data is gathered and analyzed that describes with precision and accuracy [12]. The measure phase starts with getting the voice of the customer (VOC) after the brainstorming stages in the previous tools (KJ analysis & Kano model) which provide a clear view to the customer needs that must take in the questionnaire as listed:

1- Small Size.
2- Light Weight.
3- Various powers (1 KVA, 2 KVA).
4- Product quality and general performance.
5- Low cost.
6- Product life.
7- Easy to maintain and availability of spare parts.

The questionnaires took with (30) forms in four types as in figure (7) one for the customer importance level in general and the second, third and fourth for the availability of these needs in the EIC product, Chinese product and Indian product respectively which is called benchmarking process the results can be seen in the next tables (1, 2, 3 and 4).

Customer Needs	Very unimportant 1	Unimportant 2	Low important 3	Important 4	Very important 5
Small Size	○	○	○	○	○
Light Weight	○	○	○	○	○
Various powers (1 KVA, 2 KVA)	○	○	○	○	○
Product quality and general performance	○	○	○	○	○
Low cost	○	○	○	○	○
Product life	○	○	○	○	○
Easy to maintain and availability of spare parts	○	○	○	○	○

Figure (7): Questionnaire form

Table (1): Questionnaire form 1: customer needs to be available in the product in general

No.	Customer need	Importance level
1	Small Size	3.6
2	Light Weight	3.4
3	Various powers (1 KVA, 2 KVA)	3.8
4	Product quality and general performance	4.9
5	Low cost	4
6	Product life	4.7
7	Easy to maintain and availability of spare parts	5

Table (2): Questionnaire form 2: availability of the same specifications in our product produced by EIC

No.	Customer need	availability level
1	Small Size	1.8
2	Light Weight	1.2
3	Various powers (1 KVA, 2 KVA)	1
4	Product quality and general performance	4.4
5	Low cost	2.1
6	Product life	5
7	Easy to maintain and availability of spare parts	5

Table (3): Questionnaire form 3: availability of the same specifications in a Chinese product

No.	Customer need	availability level
1	Small Size	4.4
2	Light Weight	4.9
3	Various powers (1 KVA, 2 KVA)	5
4	Product quality and general performance	3.1
5	Low cost	4.3
6	Product life	1.9
7	Easy to maintain and availability of spare parts	2

Table (4): Questionnaire form 4: availability of the same specifications in an Indian product

No.	Customer need	availability level
1	Small Size	1.6
2	Light Weight	2
3	Various powers (1 KVA, 2 KVA)	5
4	Product quality and general performance	4.4
5	Low cost	3
6	Product life	4.2
7	Easy to maintain and availability of spare parts	3.7

1.2.1. Quality Function Deployment (QFD)

Quality function deployment has been used to translate customer needs and wants into technical requirements in order to increase customer satisfaction (Akao, 1990). Quality function deployment utilizes the house of quality, which is a matrix providing a conceptual map for the design process, as a construct for understanding customer requirements (CRs) and establishing priorities of technical requirements (TRs) to satisfy them [6]. The aim of the QFD or HOQ is to determine the critical customer requirements (CCR) among list of the technical requirement analyzed and the next stages of the project will focus on these (CCR), the main steps for building the HOQ are:

1- Identify the “Whats” which are the customer requirements based on the Affinity diagram and Kano model placed on the left side of the HOQ and customer priority stated by 1 to 5 rating mentioned in the Questionnaire.

2- Establish product technical characteristics which should be measureable and meaningful they are:

- Transformer size
- Number of power transistors (MOSFET)
- Metallic body
- PCB size
- Cooling system
- Type of MOSFET
- Protection system
- Warranty
- component connection
- Microprocessor programming system

- PCB design
- Transformer design
- Availability of meters

3- Find the relationship between the customer requirement and technical characteristics using known symbols in order to determine the relationship levels (strong, medium and weak) scoring (5, 3 and 1) respectively.
4- Technical evaluation takes place by comparing with prior products or competitive products using product benchmarking placed on the right side of the HOQ.
5- Build the HOQ roof, which consists of positive and negative interactions between customer requirements and technical requirements also using symbols for (strong, medium, positive, and negative) called tradeoffs or correlation.
6- Importance ratings calculations using weighting factors for the symbols like (1-3-5, 1-3-9, 1-2-4) then multiplying it with customer importance ratings.
7- The final stage of the QFD is the analyzing of the entire matrix and finding the final product plans.

In this research the data analyzed through Microsoft EXCEL QFD template and taking the first three important technical requirements which will considered in the next stages of the project. These CCR listed in the table as following in table (5):

Table (5): most important technical requirements

No.	Technical requirements	Relative importance weighting
1	Type of MOSFET	11.4
2	Transformer Design	11.3
3	Cooling system	11.2

QFD calculations and analyzing the matrix to find the most three important characteristics among the technical requirements.

The importance weighting for each technical requirement can be calculated from the equation below [17]:

$$yi = \sum_{i=1}^{m} (pij)(xi)$$

Where:

yi = technical requirement (y1, y2, y3, ………, yn)

pij = the relationship score between customer requirements and technical requirements.

Xi = importance level for the customer requirements.

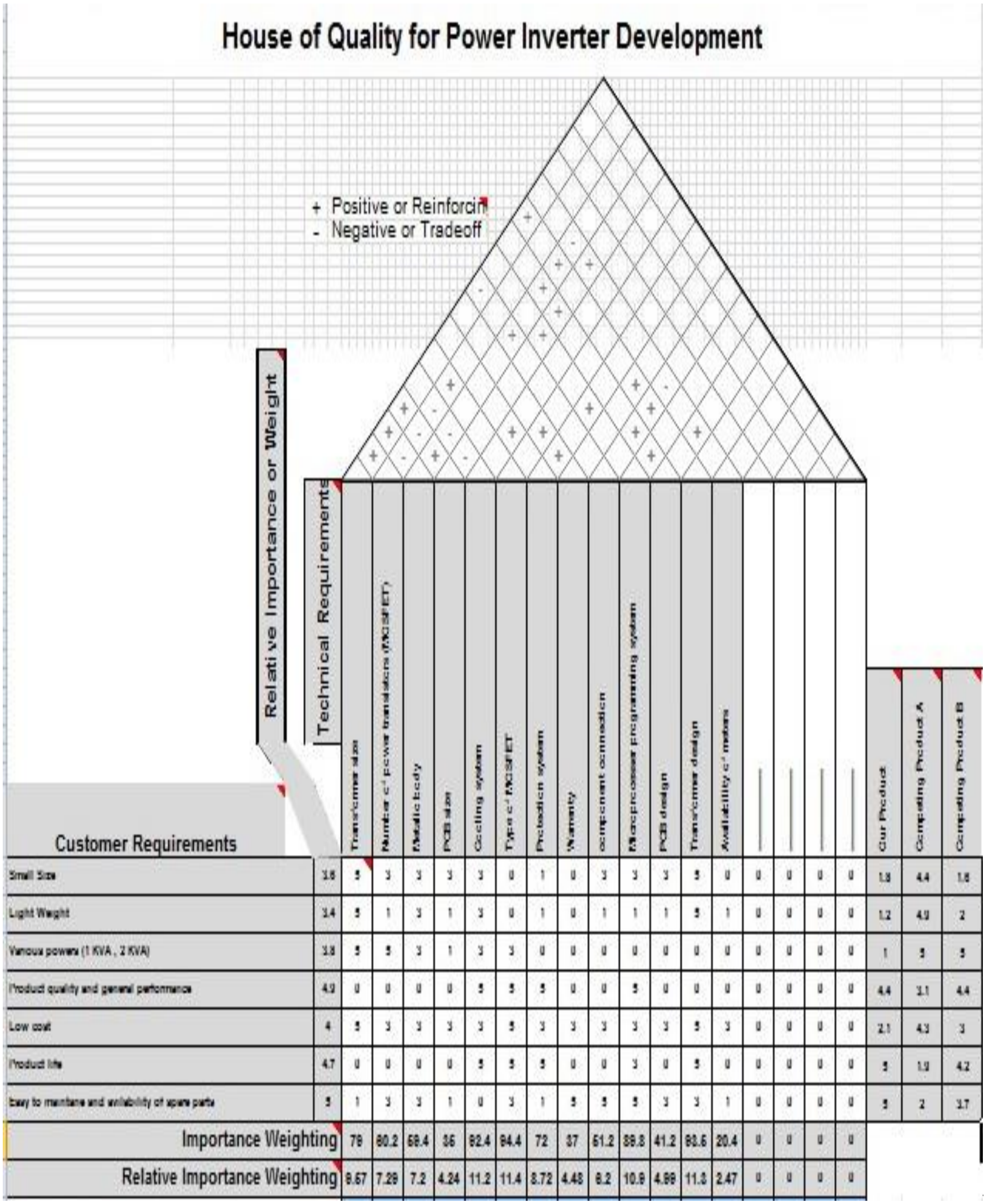
So the importance weighting for the first technical requirements (y_1) which is (transformer size) can be calculated as follows as examples:

$$y_1 = \sum(3.6 * 5) + (3.4 * 5) + (3.8 * 5) + (4.9 * 0) + (4 * 5) + (4.7 * 0) + (5 * 1) = 79$$

The Relative Importance Weighting (RIW) which is normalized importance scores can be calculated as follows taking first technical requirement (y_1) as example:

$$RIWy_1 = y_1 / \sum_1^{13} y = 0.0957 * 100 = 9.57$$

The figure (8) shows all the calculations for the HOQ of the power inverter product development.



Customer Requirements	Relative Importance or Weight	Transformer size	Number of power transistors (MOSFET)	Metallic body	PCB size	Cooling system	Type of MOSFET	Protection system	Warranty	component connection	Microprocessor programming system	PCB design	Transformer design	Availability of meters					Our Product	Competing Product A	Competing Product B
Small Size	3.6	5	3	3	3	3	0	1	0	3	3	3	5	0	0	0	0	0	1.8	4.4	1.6
Light Weight	3.4	5	1	3	1	3	0	1	0	1	1	1	5	1	0	0	0	0	1.2	4.9	2
Various powers (1 KVA , 2 KVA)	3.8	5	5	3	1	3	3	0	0	0	0	0	0	0	0	0	0	0	1	5	5
Product quality and general performance	4.9	0	0	0	0	5	5	5	0	0	5	0	0	0	0	0	0	0	4.4	3.1	4.4
Low cost	4	5	3	3	3	3	5	3	3	3	3	3	5	3	0	0	0	0	2.1	4.3	3
Product life	4.7	0	0	0	0	5	5	5	0	0	3	0	5	0	0	0	0	0	5	1.9	4.2
Easy to maintane and avilability of spare parts	5	1	3	3	1	0	3	1	5	5	5	3	3	1	0	0	0	0	5	2	3.7
Importance Weighting		79	80.2	68.4	36	92.4	94.4	72	37	51.2	89.8	41.2	93.6	20.4	0	0	0	0			
Relative Importance Weighting		8.67	7.29	7.2	4.24	11.2	11.4	8.72	4.48	6.2	10.9	4.89	11.3	2.47	0	0	0	0			

Figure (8): The House of Quality

6- Conclusion

1. The QFD considered very effective tool in determining the CCR in the cases of the company being not capable of achieving all customer requirements and there is a need to focus on the most important characteristics.
2. In developing the Power Inverter (1 KVA) produced by EIC the HOQ applied after investigating the product features by KJ analysis and Kano model tools through brainstorming which gives the QFD process a powerful information base that make the analysis results achieving high customer satisfaction.
3. QFD results where three CCRs (Type of MOSFET, Transformer Design and Cooling system) with their relative importance (11.4, 11.3 and 11.2) respectively.
4. These CCRs will have an essential role in the next stages coming in paper part II to determine (CTQ) by applying (FMEA) in (Analyze phase) to focus on particular part from the product to develop in (Design phase) and produce the product in (Verify phase) to meet customer needs.

8- References

1- Barone, Stefano, "Statistical and Managerial Techniques for Six Sigma Methodology", John Wiley and Sons, Ltd., UK, 2012, p.26.
2- Brue, Greg, "Design for Six Sigma", the McGraw-Hill companies, Inc., USA, 2003,p.4.
3- Dixit, Sanjay,Tripathi, Ambreesh and Chola ,Vikas, "800 Pure Sine Wave Inverter Reference Design", Texas, Instruments, 2013, p.3.
4- El-Haik, Basem, and Mekki, Khalid S., "Medical Device Design for Six Sigma a Road Map for Safety and Effectiveness", John Wiley & sons, Inc., Hoboken, New Jersey, 2008, p.16.
5- Fain, Nusa, Kline, Mihanel and Dohovnik, Jozel, "Integrating R&D and Marketing in New Product Development", Journal of Mechanical Engineering, 57 (2011) 7-8, pp. 549-609.
6- Gonza´lez, Marvin E., Quesada, Gioconda and Bahill, A. Terry, "Improving Product Design Using Quality Function Deployment: The School Furniture Case in Developing Countries", Marcel Dekker, Inc., QUALITY ENGINEERING Vol. 16, No. 1, pp. 47–58, 2003.
7- Harry, Mikel, & Schroeder, Richard, "Six Sigma", Doubleday a division of random house, Inc., New York, 2000, p.vii.
8- HOŘÍNKOVÁ, Barbora, PLURA, Jiří, "Possibilities of Product Quality Planning

Improvement Using Selected Tools of Design for Six Sigma", Brno, Czech Republic, EU, 2015, p.3.

9- Narayanan, H., and Khoh, S. B., "Deploying Design for Six Sigma™ in New Product Development", IEEE, 2008, pp. 1110-1115.

10- Patil, Vipin S., Andhale, Sunil R., and Paul, Izhak D., "A Review of DFSS: Methodology, Implementation and Future Research", International Journal of Innovations in Engineering and Technology (IJIET),Vol.2 Issue 1 February 2013, pp. 369-375.

11- Pavletic, Dusko and Sokovic, Mirko, "Quality Improvement Model at the Manufacturing Process Preparation Level", International Journal for Quality research, Vol.3, No. 4, pp. 309-315, 2009.

12- Pendokhare, Devendra G., Quazi, Taqui and Kulkarni, Prasad S., "Redesign and Manufacturing by Using DMADV Method", International Journal of Research in Engineering and Technology, Volume: 04 Issue: 02 | Feb-2015 pp.144-149.

13- Qiting, Pan, Uno, Nobuhiro and Kubota, Yoshiaki, "Kano Model Analysis of Customer Needs and Satisfaction at the Shanghai Disneyland", Proc. of the 5th International Congress of International Association of Societies of Design Research (IASDR), Tokyo, pp.26-30, August 2013.

14- Sankhla, Vijayendra Singh and Tege, Saurabh, "Methodology, Implementation and Future Research on Six Sigma Approach", Journal of Scientific and Engineering Research, 2015, 2(1): 47-51.

15- Selvi, K and Majumdar, Rana, "Six Sigma- Overview of DMAIC and DMADV", International Journal of Innovative Science and Modern Engineering (IJISME), ISSN: 2319-6386, Volume-2, Issue-5, pp. 16-19, April 2014.

16- Yang, Kai, and El-Haik, Basem S., "Design for Six Sigma a Road Map for Product Development", McGraw – Hill companies, Inc., USA, (2009), p.59.

17- Yang, Kai, "Voice of The Customer Capture and Analysis", McGraw-Hill companies, Inc., USA, (2008), p.242.

منهجية لستة سجما التصميم (DMADV) لتطويرالعاكسة الكهربائية

حسين سالم كيطان
أستاذ
كرار مهدي حسين
قسم الهندسة الميكانيكية
كلية الهندسة – جامعة بغداد /العراق

الخلاصة

هذا البحث يسلط الضوء على اهمية ودور (QFD) في ايجاد متطلبات الزبون الحرجة في تطوير العاكسة الكهربائية ذات الموجة الجيبية النقية (KVA1) المنتجة بواسطة الشركة العامة للصناعات الالكترونية. سوف تطبق منهجية (DMADV) والتي تمثل واحدة من منهجيات التصميم لستة سجما ((DFSS وتم تطبيقها باخذ اول مرحلتين في الجزء الاول، في المرحلة الاولى (التعريف) يتم تطبيق الادوات مخطط الاسبقية ونموذج كانو لتكوين قاعدة معلومات قوية من خلال العصف الذهني. في المرحلة الثانية (القياس) يتم استحصال صوت الزبون (VOC) بواسطة نموذج استبيان وتطبيق أداة نشر وظيفة الجودة (QFD) لايجاد الاهمية النسبية للمتطلبات التقنية ويتم اختيار اول ثلاثة منها والتي تعتبر المتطلبات الحرجة بالنسبة للزبون (CCR) وهي بالنسبة للعاكسة الكهربائية (نوع الترانزستور، تصميم المحولة، نظام التبريد)..

<u>الكلمات المفتاحية</u> : التقييم لـ6-sigm , محول الطاقة , تحليل kj , نموذج Kano , وظيفة نشر النوعية QFD .