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This is to certify that the thesis entitled "**Optimization of green electro-discharge machining using VIKOR**" being submitted by Sushil Kumar Yadav (211ME2203) for the partial fulfilment of the requirements for the degree of **Master of Technology in Production Engineering** is a bona fide thesis work done by him under my supervision during the academic year 2012-2013, in the Department of Mechanical Engineering, National Institute of Technology Rourkela, India.

The results presented in this thesis have not been submitted elsewhere for the award of any other degree or diploma to the best of my knowledge.

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Optimization of green electro-discharge machining using VIKOR

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Abstract

In the present study an efficient Multi-Criteria Decision Making (MCDM) approach has been proposed for optimization of green electro-discharge machining, because it is a commonly used non-traditional machining process. Green electro-discharge machining is a Multi-Criteria Decision Making (MCDM) problem influenced by multiple performance criteria/attributes. These criteria attributes are of two types, qualitative and quantitative. Qualitative criteria estimates are generally based on previous experience and expert opinion on a suitable conversion scale. This conversion is based on human judgment; therefore, obtained result may not be accurate always. These are analyzed using AHP, QFD, Fuzzy techniques etc. reported in literature. So to find the solution of MCDM problems there should be converted quantitative criteria values into an equivalent single performance index called Multi-attribute Performance Index (MPI). Selection of the best alternative can be made in accordance with the MPI values of all the alternatives. In this text, present study highlights application of VIKOR method adapted from MCDM techniques for obtaining the accurate result. Detail methodology of VIKOR method has been illustrated in this report through a case study.

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Chapter 1

Introduction

1.1 Introduction to decision making in the manufacturing environment

Decision making is the acknowledged process generally used in upstream of both industries and academia resulting in the selection of a course of action among a set of alternative scenario. In other way, decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision makers. On the basis of explicit assumptions analysis of individual decision is concerned with the logic of decision making which can be rational or irrational. Logical decision making is an important part of all science based professions, where specialists used their knowledge in a given area to make the decisions **[1]**.

In any industrialized nation Manufacturing work as backbone. Its importance can be measured by the fact that, in an economic activity, it comprises approximately 20 to 35% of the value of all goods and services produced. Level of manufacturing activity of a country is directly related to its economic health. So we can say that the higher the level of manufacturing activity in a country, the standard of living will be higher of its people. Manufacturing can be defined as the application of physical, mechanical and chemical processes to modify the geometry, properties and/or appearance of a given starting material in the making of new form, finished parts or products. This effort includes all intermediate processes required for the production and integration of a product's components. The ability to produce this conversion efficiently determines the success of the company. The type of manufacturing performed by a company depends on the kinds of products it makes. Manufacturing is an important commercial activity carried out by companies that sell products to customers. In the modern sense, manufacturing involves interrelated activities that include product design and documentation, material selection, process planning, production, quality assurance, management, and marketing of products.

Manufacturing technologies have continually gone through gradual but revolutionary changes. These advancements in manufacturing technologies have brought about a metamorphism in the world industrial scene. They include CNC, CAD/CAM, FMS, robotics, rapid prototyping, environmentally sustainable technologies, *etc.*, which have become an integral part of manufacturing. Parallel to this are rapid strides in the development of new products, and the emergence of an open economy leading to global competition. Manufacturing industries are compelled to move away from traditional setups to more responsive and dynamic ones. Many new concepts have emerged from these changes, sustained by strategies aimed at meeting the challenges arising from global markets. Product attributes like quality, reliability, cost, life-cycle prediction, and the organizational ability to meet market pressures like delivery and service, have come into focus. A long array of emerging technologies has opened up the potential for a variety of new products. Fast-changing technologies on the product front cautioned the need for an equally fast response from the manufacturing industries. The old, traditional model of 'unfocused, short-term views and non-holistic vision' is becoming replaced by the enlightened approach of 'focused, holistic and strategic vision'.

To meet the challenges, manufacturing industries have to select appropriate product designs, manufacturing strategies, manufacturing processes, work piece and tool materials, machinery and equipment, *etc*. The selection decisions are more complex, as decision making is challenging today. Necessary conditions for achieving effective decision making consist in understanding the current and upcoming events and factors influencing the whole manufacturing environment, in examine the nature of decision-making processes and the reach of different typologies of techniques and methods, and finally in structuring appropriately the decision-making approach based on a wide range of issues related to manufacturing systems design, planning, and management. Decision makers in the manufacturing sector frequently face the problem of assessing a wide range of alternatives, and selecting one of them based on a set of conflicting criteria.

In manufacturing sector there is wide range of alternative option for decision makers. Some of the important decision-making situations in the manufacturing environment are listed below:

- Material selection for a given engineering problem
- Evaluation of best product designs
- Evaluation of machinability for work materials
- Selection of cutting fluid for a given machining application
- Selection and evaluation of modern machining methods
- Selection and evaluation of flexible manufacturing systems
- Selection of machine's group in a flexible manufacturing cell
- Analysis of cause of failure of machine tools
- Selection of robot for a given industrial application
- Selection of automated inspection systems
- Selection of material handling equipments
- Selection of a rapid prototyping process in rapid product development
- Selection of software for design and manufacturing applications
- Selection of the most appropriate welding process for a given job
- Mouldability analysis of parts
- Evaluation of metal stamping layouts
- Selection of forging conditions for a given component
- Evaluation and examine of environmentally conscious manufacturing process
- Environmental impact estimation of manufacturing processes
- Evaluation of risk in green manufacturing

- Selection of best product end-of-life scenario
- Integrated project selection and evaluation
- Selection of facility location
- Selection of vendor in a supply chain environment

It must be noted that in choosing the right alternative, there is not always a single definite criterion of selection, so decision makers have to take into account a large number of criteria including economic, ethical, political, legal, social factors and technological. There is a need for systematic, simple, logical methods and mathematical tools to guide decision makers in considering a number of selection criteria and their interrelations.

The objective of any selection procedure is to identify the appropriate selection criteria, and find the most appropriate combination of criteria in conjunction with the real requirement. Thus, efforts need to be developed to identify those criteria that influence an alternative selection for a given problem, using simple and logical methods, to eliminate unsuitable alternatives, and to select the perfect alternative to strengthen existing selection procedures.

1.2 Decision- making methods

The methods for decision making in the manufacturing environment are:

- Graph theory and matrix approach
- Fuzzy multiple attribute decision-making methods.

Graph theory is a logical and systematic approach. The advanced theory of graphs and its applications are very well documented. Graph/digraph model representations have proved to be useful for modelling and analyzing various kinds of systems and problems in numerous fields of science and technology. If the graph/digraph is complex, it becomes difficult to analyze it visually. This can be done by computer through the use of the matrix method. An equivalent matrix of the graph/digraph model can be defined. Graph theory and the matrix approach help in identifying attributes, and offer a better visual appraisal of the attributes and their interrelations. This approach is capable of handling the inherent errors, and can deal with any number of qualitative and quantitative attributes simultaneously. The method has axiomatic foundation, involves less computation, provides great emphasis on decision-making methodology, and offers a more objective, simple and consistent decision-making approach. In addition to graph theory and the matrix approach, some other important methods, known as multiple attribute decision-making (MADM) methods, are also used in this book for decision making in the manufacturing environment.

These methods fall under the category of multiple criteria decision making (MCDM), *i.e.*, decision making in the presence of multiple, generally conflicting criteria. MCDM problems have two classifications: multiple objective decision making (MODM), and multiple attribute decision making (MADM). MODM methods have decision variable values that are determined in a continuous or integer domain with either an infinitive or a large number of alternative choices, the best of which should satisfy the decision maker's constraints and preference priorities. On the other hand, MADM methods are generally discrete, with a limited number of pre-specified alternatives. These methods require both intra- and inter-attribute comparisons, and involve explicit tradeoffs that are appropriate for the problem considered. Each decision matrix in MADM methods has four main parts, namely: (a) alternatives, (b) attributes, (c) weight or relative importance of each attribute (*i.e.*, weight), and (d) measures of performance of alternatives with respect to the attributes. Of the many MADM methods, six methods are commonly used: the weighted sum method (WSM), weighted product method (WPM), analytic hierarchy process (AHP), Revised AHP, and technique for order preference by similarity to ideal solution (TOPSIS) and compromise ranking method (VIKOR) **[2]**.

Chapter 2

Research background

Abbas et al. [3] proposed Eco friendly EDM in which model die electric fluid replaced and introducing ozonised oxygen in to EDM to eliminate harmful effects generated while machining by using dielectric fluid, to make pollution free environment through a new design of EEDM using TRIZ (a Russian acronym for Theory of Inventive Problem Solving) approach. **Tong et al. [4]** presented VIKOR method, which is a compromise ranking method used for multicriteria decision making (MCDM), which is used to optimize the multiple response process. The proposed method considers both the mean and the standard variation of quality losses associated with several multiple responses, and assure a small variation in quality losses among the responses, along with a small overall average loss. **Derringer and Suich [5]** defined a desirability function to transform several response variables into a single response. **Khuri and Conlon [6]** presented simultaneously optimized various responses using polynomial regression models. They firstly defined a distance function by considering the ideal solution, and then determined the optimal condition by minimizing this function. **Logothetis and Haigh [7]** demonstrated the use of the multiple regression method and the linear programming approach, to optimize a multi-response process using Taguchi experiments. **Phadke [8]** implemented the conventional Taguchi method to optimize individually the number of surface defects, and the thickness of the wafer and the rate of deposition in an IC manufacturing process. The optimal condition is determined by separately optimizing each response. When conflicts arise in determining the optimal level of a factor, the engineer draws upon his own knowledge to determine the best factor-level combination. **Bortolan and Degani [9]** presented the problem of ranking *n* fuzzy subsets of the unit interval. A number of techniques suggested in the literature is reviewed and tested on a group of selected examples, where the fuzzy sets can be abnormal and/or nonconvex. **Choi et al. [10]** established an assessment model for manufacturing processes in terms of environmental impact is necessary for quantitative evaluation of product design. Assessment methodology is developed on the basis of the ‘material balance’ of a process and the relationship amongst different processes. As a result, the amount of solid wastes generated, the energy consumed, the waste-water incurred as well as the level of noise are obtained. **Fava and Eston [11]** concluded that life cycle assessment has a valuable role to play in improving the understanding of and reducing the environmental burdens associated with products, processes, and activities from design and development through ultimate disposition. **Snowdon [12]** presented a tool in quantifying the environmental impact of a product or process is the use of Life Cycle Assessment (LCA). **Tipnis [13]** Developed an activity modelling (a part of the synergy methodology) and proven to be comprehensive and rigorous through a variety of system and process improvement applications in industry, because Life cycle analyses must become comprehensive and rigorous for evaluation of alternatives important to environmental decisions faced by corporations as well as regional and global organizations. **Gurocak and Whittlesey [14]** presented cost benefit analysis, which consists the conversion of all costs and benefits associated with a project into monetary terms. **Anisseh et al. [15]** Proposed a fuzzy extension of TOPSIS method for heterogeneous group decision making models under fuzzy environment which converts the decision makers fuzzy decision matrices into an aggregated decision matrix to determine the most preferable choice among all possible alternatives. **Shao et al. [16]** Presented a new approach for the problem, where cooperation degree (CD) and reliability degree (RD) are introduced for aggregating the vague experts’ opinions. Furthermore, a fuzzy multiple attributive group decision-making expert systems (FMAGDMES) is proposed to provide an interactive way to solve complex things in collaborative environment. It is an intelligent integrated system because it combines fuzzy set theory with the method of group opinion aggregation. **Stillwell et al. [17]** presented a comparison of weight approximation techniques in multi attribute utility decision making Correlations between measures of overall utility produced by each weighting technique suggest that rank weighting of dimensions results in some improvement over equal weighting. **Kuo et al. [18]** presented an innovative method, namely green fuzzy design analysis (GFDA), which involves simple and efficient procedures to evaluate product design alternatives based on environmental consideration using fuzzy logic. The hierarchical structure of environmentally conscious design indices was constructed using the analytical hierarchy process (AHP), which include five aspects: (1) recycling, (2) energy, (3) toxicity, (4) cost, and (5) material. After weighting factors for the environmental attributes are determined, the most appropriate design alternative can be selected based on the fuzzy multi-attribute decision making (FMADM) technique. The benefits of using such a technique are to effectively solve the design problem by capturing human expertise. And also presented an efficient green fuzzy analysis method to allow designers evaluate different design alternatives and come up with an environmentally benign product design**. Lai et al. [19]** Presented the report in which results of a case study where the analytic hierarchy process (AHP) technique was employed to support the selection of a multi-media authorizing system (MAS) in a group decision environment. The experiment results and survey findings indicated that the AHP is preferable to Delphi as the AHP helps group members centre a discussion upon objectives, rather than alternatives. **Opricovic and Tzeng [20]** Presented the VIKOR method to solve MCDM problems with conflicting and non commensurable (different units) criteria, assuming that compromising solution is acceptable for conflict resolution, the decision makers want a solution that is the closest to the ideal, and the alternatives are evaluated according to all established criteria. This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria, and on proposing compromise solution (one or more). The VIKOR method is developed with a stability analysis determining the weight stability intervals and with trade-offs analysis.

The developed VIKOR method is compared with three multicriteria decision making methods: TOPSIS, PROMETHEE, and ELECTRE. **Triantaphyllou [21]** presented a methodology for performing a sensitivity analysis on the weights on the decision criteria and the performance values of the alternatives expressed in terms of the decision criteria. The proposed methodology is established on three widely used decision techniques. These methods are the weighted sum model (WSM), the weighted product model (WPM), and the analytic hierarchy process (AHP). This paper formalizes a number of important issues on sensitivity analysis and derives some critical theoretical results. **Zanakis et al. [22]** presented comparison of select methods for solving multi-attribute decision making problems (MADM). A major criticism of MADM is that different techniques may yield different results when applied to the same problem. The considered problem in this case study consists of a decision matrix input of N criteria weights and ratings of L alternatives on each criterion. The performances are compared of some methods has been investigated in a few, mostly field, studies. In this simulation experiment investigate the performance of eight methods: ELECTRE, TOPSIS, Multiplicative Exponential Weighting (MEW), Simple Additive Weighting (SAW), and four versions of AHP (original vs. geometric scale and right eigenvector vs. mean transformation solution). Counterfeit parameters are the number of alternatives, criteria and their distribution. The solutions are examined using twelve measures of similarity of performance. Likeness and differences in the behaviour of these methods are investigated. Dissimilarities in weights produced by these methods become stronger in problems with few alternatives; however, the comparable final rankings of the alternatives vary across methods more in problems with many alternatives. Although less important, the distribution of criterion weights affects the techniques differently. In general, all AHP types' methods behave similarly and closer to SAW than the other methods. ELECTRE is the least similar to SAW (except for closer matching the top-ranked alternative), followed by MEW. TOPSIS behaves closer to AHP and differently from ELECTRE and MEW, except for problems with few criteria. A similar kind of rank-reversal experiment produced the following performance order of methods: SAW and MEW (best), followed by TOPSIS, AHPs and ELECTRE. **Gupta [23]** Introduces that, corporations have been confronted with a number of global environmental challenges such as acid rain, global warming, depletion of natural resources, waste generated, green consumerism and pollution problem. There is growing pressure to deliver products and services which are environmentally conscious. A number of corporations such as 3M, Du Pont, AT&T, Xerox and Procter & Gamble are, therefore, combining various environmental policies and programmes into their operations strategy and specific decisions concerning operations such as product design, product planning, selection of process technology, and quality management. Introduces the concepts of environmental management (EM) and argues that firms which do not recognize the implications of environmental problems on the operations function will not succeed in the competitive world. Various environmental management forms (such as implementing aggressive pollution-prevention programmes, initiating environment-related performance measures and developing green products and process technologies) provide opportunities to strengthen a firm's distinctive competence in terms of operations objectives such as lowest cost, highest quality, greatest flexibility and best dependability. Thus, EM gives an ambitious advantage and develops new links between operations strategy and the corporate strategy (e.g. cost leadership and product differentiation). **Ribeiro [24]** reviewed the main theories and methods used for multiple attribute decision making in a fuzzy manufacturing environment. Fuzzy multiple attribute decisions involve two processes, the rating of alternatives and the ranking of alternatives. If the rating results are fresh then the ranking procedure becomes straightforward; hence, the attention of this paper is on obtaining fresh ratings for alternatives. In order to assist the decision maker to express his/her attribute preferences, new selection techniques to determine attributes importance are proposed. **Fiksel [25]** developed the concept of Design for Environment (DfE), which originated in 1992 with the efforts of many electronics firms that attempted to build environmental awareness into their product development tasks. DfE is defined as the *"systematic consideration of design performance with respect to health, environmental and safety objectives over the full product and process life cycle."* The forces which drives DfE include the fact that costumers have become increasingly concerned about the environmental friendliness of the products they acquire. As Finksel points out "*DfE is at the crossroads of two trusts that are transforming the nature of manufacturing in the world"*, and this makes interesting concept from a systems thinking perspective. DfE combines and gives the results from the interaction between two systems, the environmental system and the economics system and branches out into two areas of action: feasible development, which main aims at designing industrial progress that *"meets the needs of the present without compromising the ability of future generations to meet their own needs"*; and enterprise integration, which is concerned with factoring environmental concerns into the profitability and effectiveness of the firm. **Watkins et al. [26]** described a general and uniform way to analyze the environmental impact of manufacturing based on the product decay, the materials used in the manufacturing processes, and the circumstantial view of the environment. The goal of environmentally conscious design for manufacturing is to select materials and processes that minimize environmental impact. To accomplish this task, we developed a computer program, called EcoSys$^{\mathcal{M}}$, that assists manufacturing engineers and environmental reviewers in assessing the environmental consequences of their manufacturing decisions. **Tong and Su [27]** presented a conventional approach used in off-line quality control is the Taguchi method. However, most of Taguchi method applications have only dealt with a single-response problem and the multi-response problem has received only limited application. The theoretical analysis in this case study reveals that Taguchi's quadratic loss function and the indifference curve in the TOPSIS (Technique for order preference by similarity to ideal solution) method have parallel features. The Taguchi method deals with a one-dimensional problem and TOPSIS handle multi-dimensional problems. As a result, the relative closeness coefficient computed in TOPSIS can be used as a performance measurement index for optimizing multi-response problems in the Taguchi method. **Pandey and Kengpol [28]** presented a methodology for selecting the best possible automated inspection device for use in flexible manufacturing systems. This problem has been modelled as that of multi criterion decision making and solved using Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). **Sayadi et al. [29]** presented the VIKOR method for multi-criteria optimization of complex systems, which determines the compromise ranking list and the compromise solution obtained with the initial weights. This method targets on ranking and selecting from a set of alternatives in the presence of conflicting criteria. It recommends the multi-criteria ranking index based on the particular measure of ‘‘closeness” to the ‘‘ideal” solution. The main aim of this paper is to develop the VIKOR method for decision making problems with interval number. The developed VIKOR method’s ranking is obtained through comparison of interval numbers and for doing the comparisons between intervals. **Ju and Wang [30]** proposed a new method to solve multi-criteria group decision making problems in which both the criteria values and criteria weights take the form of linguistic information based on the traditional idea of VIKOR method. Firstly, the linguistic criteria weights given by all decision makers are transformed into trapezoidal fuzzy numbers, and then aggregated and de fuzzified to crisp values. Secondly, the individual linguistic decision matrix given by each decision maker (DM) is transformed into 2-tuple linguistic decision matrix, and then aggregated into collective 2-tuple linguistic decision matrix by 2-tuple linguistic arithmetic mean operation. Thirdly, the 2-tuple linguistic values $(S_i, \alpha_i), (R_i, \alpha_i)\ and\ (Q_i, \alpha_i)$ are calculated by defining the 2-tuple linguistic positive ideal solution (TL-PIS) and 2-tuple linguistic negative ideal solution (TL-NIS). Furthermore, the compromise solution can be obtained. **Yang et al. [31]** proposed integrated fuzzy multiple criteria decision making (MCDM) method addresses this issue within the context of the vendor selection problem. First, use triangular fuzzy numbers to express the subjective preferences of evaluators. Second, use interpretive structural modeling (ISM) to map out the relationships among the sub-criteria. Third, use the fuzzy analytical hierarchy process (AHP) method to compute the relative weights for each criterion, and use non-additive fuzzy integral to obtain the fuzzy synthetic performance of each common criterion. Fourth, the best vendor is founded according to the overall aggregating score of each vendor using the fuzzy weights with fuzzy synthetic utilities. Fifth, use an empirical example to show that our proposed method is preferred to the traditional method, especially when the sub-criteria are interdependent. **Yang et al. [32]** proposed an information security risk-control assessment model that could improve information security for these companies and organizations, also proposed an MCDM model combining VIKOR, DEMATEL, and ANP to solve the problem of conflicting criteria that show dependence and feedback. In extension, an empirical application of evaluating the risk controls is used to illustrate the proposed method. The results show that proposed method can be effective in helping IT managers validate the effectiveness of their risk controls. **Hsu et al. [33]** proposed how the best selection to conduct the recycled materials can be implemented for enhancing and increasing the efficiency of using resources in the manufacturing process through recycled materials VS. Aluminium composite panel (ACP) is a global product, and ACP companies in Taiwan use recycled materials in more than 80% for their products on a quantity basis. Therefore, selected the ACP industry of Taiwan as an empirical model to study VS and to reveal methods of improving gaps in each criterion for achieving the aspired levels of performance, also use the MCDM model combining DEMATEL-based on ANP (called DANP) with VIKOR to solve the recycled materials VS problems of multiple dimensions and criteria which interdependent, instead of the independent assumption of an analytic hierarchy process, for performing the real-world scenario. **Chiu et al. [34]** focused on assessing and improving strategies to reduce the gap of customer satisfaction caused by interdependence and feedback problems among dimensions and criteria to achieve the aspiration level, and proposed a new hybrid Multiple Attribute Decision Making (MADM) model, combining the Decision Making Trial and Evaluation Laboratory (DEMATEL), DEMATEL-based Analytic Network Process (DANP), and VIšekriterijumsko KOmpromisno Rangiranje (VIKOR) methods to solve these problems. Then, three real cases are used to explain how the proposed new hybrid Multiple Criteria Decision-Making (MCDM) model improves e-store business. These results can provide a knowledge- based understanding to e-store managers of how to create marketing strategies that minimize the performance gaps of dimensions and criteria to satisfy consumers' needs and encourage customers to purchase more and more.

Shemshadi et al. [35] developed the VIKOR method was developed to solve multiple criteria decision making (MCDM) problems with conflicting and non-commensurable criteria assuming that compromising is acceptable to resolve conflicts. On the other side objective weights based on Shannon entropy concept could be used to regulate subjective weights assigned by decision makers or even taking into account the end-users' opinions to solve multiple criteria decision making (MCDM) problems with conflicting and non-commensurable criteria assuming that compromising is acceptable to resolve conflicts. On the other side objective weights based on Shannon entropy concept could be used to regulate subjective weights assigned by decision makers or even taking into account the end-users' opinions. **Wu [36]** discussed multiple criteria decision making (MCDM) problems in manufacturing systems. Optimization has been used to achieve the greatest utilization of resources and satisfy as many constraints as possible. This activity can be implemented by formulating the multiple objective functions subject to various constraints. However, when the flow of information in manufacturing systems is increased, mathematical models may be - difficult to formulate the interrelationships and connections among those units in the system. To satisfy two conflict goals in manufacturing environment: flexibility and productivity, decision making problem in manufacturing systems such as part selection problem could be very complicated, especially in an FMS.

2.1 Motivation of the present work

Lots of MCDM techniques are available in the literature of various fields; so this is important for analyser which technique should be used when confronted in a decision-making cum selection problem. If this made casually, the entire design may be wrong, resulting in a weak solution. This in turn results waste of time, money, resources, and energy. Though all the criterions correspond to qualitative and vague information in general decision making practice, a robust, accurate MCDM technique is indeed required for the best compromise solution. Therefore, for today's researcher it is very difficult job to apply the appropriate method. But best method doesn't always accurate method, so the best method is that one which provide the optimize solution.

The objective of the current work is to provide a robust, quantified MCDM monitor of the *level of- satisfaction* among the decision makers and capability to tackle vague-incomplete information and uncertainty in real life application followed by the case study viz. *1. Multi-attribute decision making for green electro-discharge machining.*

2.2 Organization of the thesis

The entire thesis has been organized in four chapters. **Chapter 1** presents the concept of decision making in manufacturing environment and theory of MCDM followed by its category of classification and field of application. **Chapter 2** presents an extensive literature survey and also depicts the applicability in MCDM and also covers a section highlighting motivation of the current research. **Chapter 3** covers presentation of concept of MADM and necessary mathematical background on MADM method and related conceptual definitions of some used MADM methods. In this chapter, readers may get a clear understanding with root mathematical concept of VIKOR method and importance of linguistic variables in the course of multiple conflicting decision making problems. **Chapter 4** illustrate the applicability of recent methodologies in green EDM respectively under manufacturing environment as a case study. **Chapter 5** covers optimization procedure, and **Chapter 6** covers the results and discussion. Finally, concluding remarks of this dissertation have been presented in subsequent chapter end.

Chapter 3

Mathematical background

3.1 Concept of MADM

The historical origins of MADM can be traced back to correspondence between Nicolous Bernoulli (1687-1759) and Pierre Remond de Montmort (1678-1719), discussing the St. Petersburg game denotes the problem

A game is played by flipping a fair coin until it comes up tails and the total number of flips, n, determines the prize, which equals \$2$\times n$. If the coin comes up heads the first time, it is flipping again, and so on. The problem arises: how much are you willing to pay for this game.

According to the expected value theory, it can be calculated that $EV = \sum_{n=1}^{\infty}(1/2)^n \times 2^n$ and the expected value will go to infinity. After solving this problem will get a result, which goes against human behaviour since no one is willing to pay more than 1000 $ for this game. The answer to the St. Petersburg paradox was unavailable until Daniel Bernoulli (1700-1782) published his influential research on utility theory in 1738. We ignore the concrete discussions describing the solution of the St. Petersburg paradox in detail but focus on the conclusion that humans make decisions based not on the expected value but the utility value. The implication of the utility value is the humans choose the alternative with the highest utility value when confronted the MADM problems **[37].**

Systematically approaching these types of problems is solved by a general process called multi-attribute decision analysis (MADA). The MADA process consists of four stages;

- Framing of the decision and identification of the goals and objectives which is achieved by the decision maker
- Identification of all decision alternatives and any related attributes that address the decision making objectives

- Specification of preferences, both for each of the individual attributes and between the attributes in the framework
- Ranking of the decision alternatives according to the specified preferences, given the attribute data for each of the alternatives.

3.2 Coverage

The Taguchi method **[5]** implement offline experimental technique for improving quality in industry. To perform experiments Taguchi used an orthogonal array and employed the signal-to-noise (S/N) ratio as the quality measurement index, with simultaneous consideration of the mean and variability of the quality characteristic, to determine the optimal setting of process parameters. In industry the effectiveness of the Taguchi method for improving quality has been extensively verified. However, most of the method optimizes only a single response. If more than one response is to be optimized, engineers usually set the optimal factor-level combination from their experience. Such behaviour is neither objective nor systematic. In recent years some procedures have been developed for optimizing multi response problems, however, these procedures cannot explain the variation in quality losses among multiple responses. The optimal factor-level combination can be determined using these procedures, may result in small quality losses associated with some responses but very large losses associated with others, even if the average quality loss is sufficiently small. Some methods for optimizing several responses have been developed that use complex statistical models and are impractical for application by engineers who do not have a strong background in mathematics. Therefore, a new approach is proposed for solving the optimization problem for multi response processes using the VIKOR method. The MCDM procedure can be employed to optimize the solution having several alternatives with conflicting and compromising multi criteria. The VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian) method **[39-41]** is applied to derive an integrated quality measurement of several conflicting and compromising responses. Firstly, the positive ideal and negative-ideal solutions are initially determined from the quality loss. Secondly, the utility measure and the regret measure of each alternative are determined according to the weight of each criteria. Thirdly, the VIKOR index of each experimental run is obtained using the corresponding utility and regret measures. Finally, the main effect of the VIKOR index is determined and the optimal factor-level combination is thus obtained.

3.3 VIKOR method

The MCDM method is very popular technique widely applied for determining the best solution among several alternatives having multiple attributes or alternatives. A MCDM problem can be presented by a decision matrix as follows:

$$D= \begin{array}{c} \\ A_1 \\ A_2 \\ \\ \\ \\ A_m \end{array} \begin{bmatrix} Cx_1 & Cx_2 & \cdot & \cdot & \cdot & \cdot & \cdot & Cx_n \\ x_{11} & x_{12} & \cdot & \cdot & \cdot & \cdot & \cdot & x_{1n} \\ x_{21} & x_{22} & \cdot & \cdot & \cdot & \cdot & \cdot & x_{2n} \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ x_{m1} & x_{m2} & \cdot & \cdot & \cdot & \cdot & \cdot & x_{mn} \end{bmatrix}$$

Here, *i A* represents *ith* alternative, i =1, 2,.........,m; j Cx represents the *jth* criterion, j =1, 2,.........,n ; and x_{ij} is the individual performance of an alternative. The procedures for evaluating the best solution to an MADM problem include computing the utilities of alternatives and ranking these alternatives. The alternative solution with the highest utility is considered to be the optimal solution. The following steps are involved in VIKOR method**[9]**.

Step 1: Representation of normalized decision matrix

The normalized decision matrix can be expressed as follows:

$$F=\left[f_{ij}\right]_{m\times n} \tag{1}$$

Here, $f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$, i=1,2,$\cdots, m$; and x_{ij} is the performance of alternative A_i with respect to the jth criterion.

Step 2: Determination of ideal and negative-ideal solutions

The ideal solution A^* and the negative ideal solution A^- are determined as follows:

$$A^* = \left\{\left(max f_{ij} \middle| j \in J\right) or \left(min f_{ij} \middle| j \in J'\right), i = 1,2,\cdots\cdots, m\right\} = \left\{f_1^*, f_2^*, \cdots f_j^*, \cdots f_n^*\right\} \tag{2}$$

$$A^- = \left\{\left(min f_{ij} \middle| j \in J\right) or \left(max f_{ij} \middle| j \in J'\right), i = 1,2,\cdots\cdots, m\right\} = \left\{f_1^-, f_2^-, \cdots f_j^-, \cdots f_n^-\right\} \tag{3}$$

where, $J = \left\{j = 1,2,\cdots, n \middle| f_{ij}, if\ desire\ response\ is\ large\right\}$

$J' = \left\{j = 1,2,\cdots, n \middle| f_{ij}, if\ desire\ response\ is\ small\right\}$

Step 3: Calculation of utility measure and regret measure

The utility measure and the regret measure for each alternative are given as

$$S_i = \sum_{j=1}^{n} w_j \frac{\left(f_j^* - f_{ij}\right)}{\left(f_j^* - f_j^-\right)} \tag{4}$$

$$R_i = \underset{j}{Max} \left[w_j \frac{\left(f_j^* - f_{ij}\right)}{\left(f_j^* - f_j^-\right)}\right] \tag{5}$$

where, S_i and R_i , represent the utility measure and the regret measure, respectively, and w_j is the weight of the *jth* criterion.

Step 4: Computation of VIKOR index

The VIKOR index can be expressed as follows:

$$Q_i = \upsilon \left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - \upsilon) \left[\frac{R_i - R^*}{R^- - R^*}\right] \tag{6}$$

where, Q_i , represents the *ith* alternative VIKOR value, i =1, 2,........,m;

$S^* = \underset{i}{Min}(S_i)$, $S^- = \underset{i}{Max}(S_i)$, $R^* = \underset{i}{Min}(R_i)$, $R^- = \underset{i}{Max}(R_i)$ and υ is the weight of the maximum group utility (usually it is to be set to 0.5 **[38-40]**). The alternative having smallest VIKOR value is determined to be the best solution.

3.4 Procedure adopted in VIKOR method

There are some methods which are used to solve simultaneous optimizing multi-response problems, but they neglect the variation among quality losses associated with the various responses. The optimal factor-level combination generates an variable quality loss among responses which is unacceptable to customers. A systematic approach is presented here in to solve this problem known as multi response optimization. The VIKOR method in MADM is engaged to optimize the solution to the multi-response problem. The proposed procedure is that, firstly calculates the positive-ideal and negative-ideal solutions of each experimental run by considering the quality loss and weight of each response, and then the calculate utility and regret measures. Then VIKOR index is calculated by weighting the utility and regret measures of each experimental run. The developed VIKOR index can help to determine the optimal setting of parameters. The proposed optimization procedure is as follows **[4]**.

Step 1: Estimation of quality loss

Taguchi **[8]** defined quality loss estimates for responses using Lower-the-better (LB) and Higher-the-better (HB) criterion are given bellow.

For a Lower-the-Better (LB) attribute:

$$L_{ij} = k_1 \times \frac{1}{r}\sum_{k=1}^{r} y_{ijk}^2 \quad (7)$$

For a Higher-the-Better (LB) attribute:

$$L_{ij} = k_2 \times \frac{1}{r}\sum_{k=1}^{r} y_{ijk}^2 \tag{8}$$

Here, L_{ij} is the quality loss associated with the *jth* attribute in the *ith* experimental run; y_{ijk} is the observed *kth* repetition datum for the *jth* attribute in the *ith* experimental run; r is the number of repetitions for each experimental run. k_1 , k_2 are quality loss coefficients, i =1, 2,........,m; j =1,2,.......,n ; k =1,2,........, r .

Step 2: Calculation of normalized quality loss (NQL) for individual attributes in each experimental run. The NQL can be obtained as follows:

$$f_{ij} = \frac{L_{ij}}{\sqrt{\sum_{i=1}^{m} L_{ij}^2}} \tag{9}$$

Here f_{ij} represents the NQL of the *jth* attribute in the *ith* experimental run.

Step 3: Evaluation of ideal and negative-ideal solutions. A smaller NQL is preferred, so the ideal and negative-ideal solutions which represent the minimum and maximum NQL of all experimental runs are as follows:

$$A^* = \{min f_{ij} | i = 1,2, \cdots\cdots, m\} = \{f_1^*, f_2^*, \cdots\cdots, f_j^*, \cdots\cdots, f_n^*\} \tag{10}$$

$$A^- = \{max f_{ij} | i = 1,2, \cdots\cdots, m\} = \{f_1^-, f_2^-, \cdots\cdots, f_j^-, \cdots\cdots, f_n^-\} \tag{11}$$

Step 4: Calculation of the utility and regret measures for each response in each experimental run using **Eq. (4, 5)** respectively.

Step 5: Calculation of VIKOR index of the *ith* experimental run. Substituting S_i and R_i into equation (6) yields the VIKOR index of the *ith* experimental run as follows. A smaller VIKOR index produces better multi-response performance.

Step 6: Determination of optimal parametric combination the multi-attribute quality scores for each alternative can be determined from the VIKOR index obtained in step 5. The best one is finally determined, in view of the fact that a smaller VIKOR value indicates a better quality.

Chapter 4

Electro-discharge machining

Electro-discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. EDM process is based on thermoelectric energy. Thermoelectric energy generated between the work piece and an electrode. A pulse discharge occurs between the work piece and the electrode in a small gap and removes the unwanted material from the parent metal through melting and vaporising. In order to generate the spark the electrode and the work piece must have electrical conductivity. There are various types of products which can be produced using EDM such as dies and moulds. Parts of aerospace, automotive industry and surgical components can be finished by EDM **[3]**.

4.1 Coverage

Electro-Discharge Machining is suitable for machining very hard and brittle materials. Now a day's in EDM there are many advances technology which makes it valuable and viable process in manufacturing environment. That's why now EDM is suitable for manufacturing of critical parts such as aerospace and aeronautical components.

There are many advantages of EDM process but it has many disadvantages like EDM is considered as a hazardous process in which large amounts of toxic solid and liquid wastes and exhaust gas are discharged, resulting in serious occupational and environmental problems **[42]**. EDM process discharge high energies and due to these high energies there are arising a number of reaction-products of the dielectric, which can emit from its surface as aerosols or gases. Apart from the air emissions in this process, hazardous substances can also concentrate in the slurry and dielectric itself. These toxic substances are very harmful because they can enter the body of operating personnel through ingestion, inhalation and skin contact. The performance characteristics of this process and the amount of waste generated from it are strongly influenced by the process parameters. Thus optimization of process parameters is an essential requirement to achieve green EDM. So we have to select the optimum process parameters to achieve green manufacturing. The main objective of this work is to select optimum process parameters for EDM which best reflect the manufacturing priority between environmental and machining factors. The experiments are designed using Taguchi L9 orthogonal array. An analytical model is developing for optimizing the process parameters. Peak current, pulse duration, dielectric level and flushing pressure were the process parameters considered in this study. Then, a VIKOR method has been proposed to deal with the process parameters selection problems in the EDM. A case study has been illustrated an application of the proposed model.

4.2 Introduction

In today's' competitive Manufacturing sector, EDM process has become a major concern for every industry. This technique also used for finishing parts for aerospace and automotive industry and surgical components **[43]**. This technique has been developed in the late 1940s **[44]** where the process is based on removing material from a part by means of a series of repeated electro discharges between tool called the electrode and the work piece in the presence of a dielectric fluid **[45]**. To ionize the dielectric we have to keep electrode toward the work piece until the gap is small enough so that the impressed voltage is great enough. Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece **[46]**. The material is removed due to the thermal energy generated in the discharge channel. Heat generated in the channel causes some of the work material to melt and even evaporate. As the spark collapses, the evaporated metal and part of the molten metal are carried away by the dielectric fluid which is flushed using pressure **[3]**. There is not direct contact between the electrode and the work piece where it can eliminate mechanical stresses chatter and vibration problems during machining in EDM process **[43]**. Materials of any hardness can be cut as long as the material can conduct electricity **[47]**. EDM process has developed in many fields. Trends on activities carried out by the researchers depend on the interest of the researchers and the availability of the technology. In a book published in 1994, Rajurkar **[48]** has indicated some future trends activities in EDM: machining advanced materials, mirror surface finish using powder additives, ultrasonic-assisted EDM and control and automation.

From literature review, it has been observed that, choosing a suitable and efficient methodology to solve a multi-criteria decision making problem and selecting the best alternative is a great challenge to the researchers as well as management practitioners due to the existence of conflicting and non-commensurable criteria associated with green manufacturing problem. To overcome this shortcoming, in the present reporting VIKOR based Multi attribute Decision Making approach has been proposed to utilize exact numeric values of quantitative parameters (quality and performance indices).

4.3 Input-process-output diagram of EDM process

Choi et al. [10] proposed a modified form of input-process output model as shown in F**igure 1** shows the relationship between the process parameters and output responses. The inputs of the process consists

The following four process parameters are used in this case study:

- peak current
- voltage
- pulse duration
- flushing pressure

Input for process includes work piece, tool and dielectric fluid, and electrical energy.

- Work
- Tool
- Dielectric
- Electric energy

Outputs of this process includes material removal rate, tool wear rate, air emissions, dielectric wasted in the form of liquid, eroded work and tool materials, heat and noise.

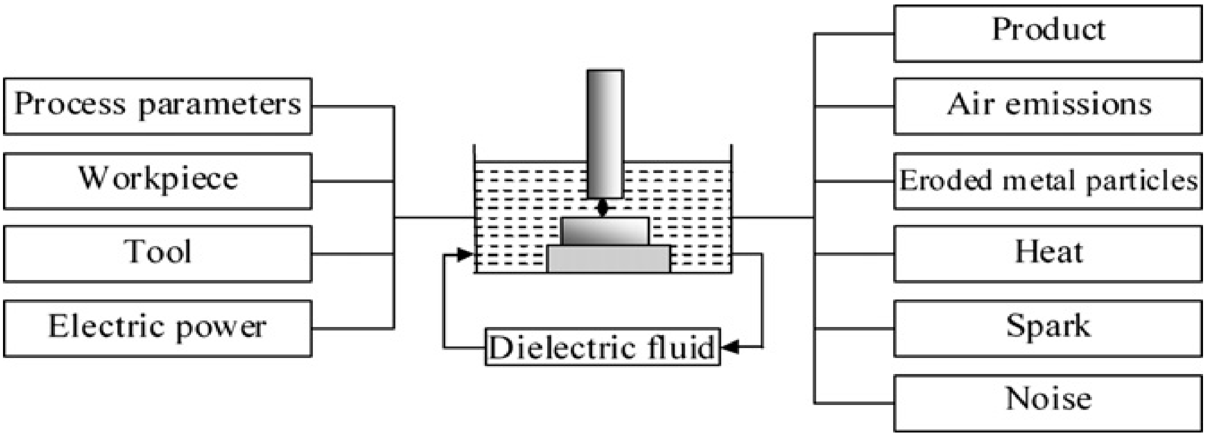

Figure 1 : Input-process-output diagram of EDM process [49]

In EDM process, an electric arc struck between two electrodes produces the energy required for the material removal. The process is carried out in a dielectric medium. As thermal energy generated in discharge channel results high temperature reached by the surface of both the electrodes and this is the main cause of material removal. Some of the work material melt and even evaporate due to heat generated in channel. **Abbas et al. [3]** found that as the spark collapses, the evaporated metal and part of the molten metal are carried away by the dielectric fluid which is flushed using pressure.

4.4 Decision making model for green EDM

Decision making model consists of the following two types of attributes as shown in **Figure 2.**

- Manufacturing
- Environmental

Each attribute is related to several output parameters. There are five output parameters as shown in **Figure** 2. In this model two output parameters are considered under manufacturing attribute and three output responses are under environmental attribute.

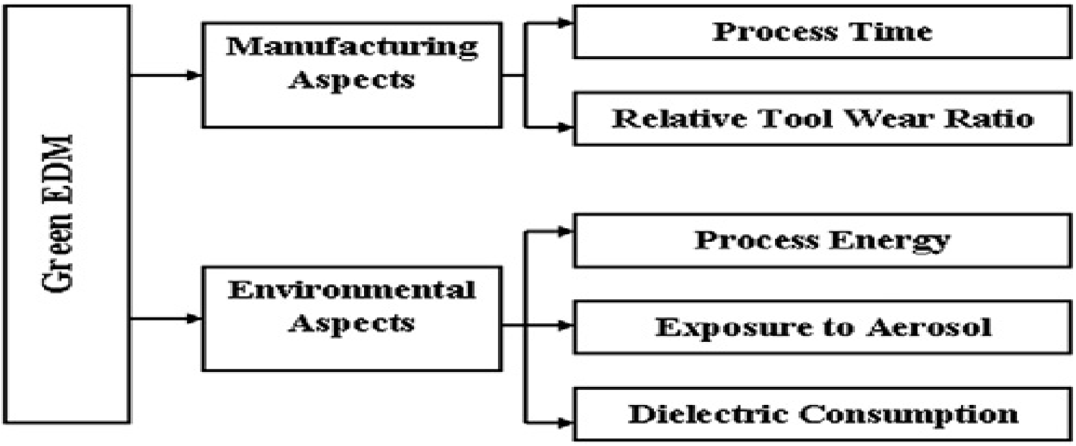

Figure 2 : Decision making model for green EDM [49]

- **Process time**

In the EDM process material removal rate is the most important machining parameter in the EDM process. Machining time and cost of operation determines by MRR. In present work for unit material removal time required is considered as a factor.

- **Relative tool wear ratio**

During EDM process high electric discharge is generated and some of this discharge energy affects the tool material as this energy produces a crater wear in tool material. This tool wear affect the cost of operation as well as the amount of waste generated. The amount of erosion suffered by the tool compared with that of the work piece was referred to as the relative tool wear ratio.

- **Process energy**

EDM process consumed electrical energy and this electrical energy indirectly affects environment. To generate the more electricity more waste is produced by electrical energy. For unit material removal energy consumed will be response variable for this case study. This energy can be determined by the gap voltage during discharge, the discharge current and the length of time that the current flows.

- **Breathing zone concentration of aerosol**

When hydrocarbon dielectric fluid is used Occupational exposure to toxic aerosols is an important hazard potential of the process particularly. The aerosol generated from the process may consist of metallic particles and reaction products of the dielectric material. Mass concentration of respirable particulates in the breathing zone of the operator was considered as a factor in the case study.

- **Dielectric consumption**

Yeo et al. [50] found that During the EDM process, the dielectric fluid is generally wasted through three paths

- Coating of the dielectric fluid on the work piece.
- Coating of the dielectric fluid on materials removed from both the work piece and tool.
- Vapour of the dielectric diffused into the surrounding environment.

During the process consumed dielectric has environmental impacts. The wasted dielectric in the form of gas and liquid may cause problems to the operators as well as the environment. In the present case study the mass of dielectric consumed per unit material removal is considered as a factor.

4.5 Materials and method

The experiments were conducted on a conventional die sinking electro-discharge machine manufactured by Victory Electromech. A high carbon high chromium tool steel plate of size 4 cm× 4 cm× 1.5 cm was used as the work piece and a copper rod of diameter 25 mm was used as the tool. Commercially available kerosene was used as the dielectric fluid and side flushing was opted. Kerosene is a blend of hydrocarbons (C12–C15) which is widely used in EDM because of its high flash point, good dielectric strength, low viscosity and low specific gravity. The open gap voltage was kept constant at 100 V. Duty factor was kept at 0.5. During the machining, the tool 'jumped' periodically to a height of 1.25 mm to clean the gap between the work piece and tool. The machining was interrupted at each jump. The jump duty cycle (ratio of machining time to the total time) was kept at 0.75. Aerosol in the process location was sampled using a Universal Air Sampler (SKC model No. 224-PCXR8) with cyclone attachment. The cyclone attachment was used to separate particles of size 5 lm and above which are not respirable. A PVC filter of diameter 37 mm was used as the sampling medium. Samples of the aerosol were taken at a sampling point of 200 mm vertical distance and 200 mm horizontal distance from the dielectric surface above the process location. This location was assumed to correspond to an operators breathing zone in the worst case. The velocity of the sampler was kept at 2.5 l/min and the sampling was done for duration of 8 h. The sampler was calibrated before and after sampling using a soap bubble meter, with the sampling medium in line. The weight of the filter paper was measured before and after sampling using a sensitive balance (accuracy ±0.01 mg) **[49].**

4.5.1 Determination of output parameters

➢ **Concentration of aerosols (C_A)**

Concentration of aerosols in the work atmosphere can be calculated from the **Eq. 12.**

$$C_A = \frac{(W_{fb} - W_{fa}) \times 1000}{t_s \times \upsilon} \tag{12}$$

where W_{fa} and W_{fb} are the weights of filter paper in mg, before and after sampling, t_s is the sampling duration in minutes and v is sampling speed in l/min.

➢ **Material removal rate (MRR)**

Material removal rate and the tool wear rate (TWR) can be calculated by taking the weights of the work piece and tool before and after the experiment. MRR can be calculated from **Eq. 13.**

$$MRR = \frac{(W_{Wa} - W_{Wb})}{t_m} \tag{13}$$

where W_{Wa} andW_{Wb} are the weights of work piece in mg, before and after machining and t_m is the machining time.

TWR can be calculated from **Eq. 14.**

$$TWR = \frac{(W_{Ta} - W_{Tb})}{t_m} \tag{14}$$

where W_{Ta} and W_{Tb} are the weights of tool in mg, before and after machining and t_m is the machining time.

➢ **Process time (T)**

Process time is the time taken in seconds to remove 1 mg of material. This factor can be calculated using the **Eq. 15**, as shown below

$$T = \frac{60}{MRR} \tag{15}$$

- **Relative tool wear ratio**

Relative tool wear ratio is the ratio of tool wear ratio and material removal rate as shown by the **Eq. 16.**

$$RTWR = \frac{TWR}{MRR} \tag{16}$$

- **Process energy (E)**

Process energy is the energy in used to remove 1 mg of material. This can be calculated using the following **Eq. 17.**

$$E = f_d \times f_j \times V \times I \times T \tag{17}$$

where f_d, f_i, V, and I are the duty factor, jump factor, gap voltage and peak current, respectively.

- **Dielectric consumed (D_c)**

Dielectric consumed for removing 1 mg of material (D_c) is calculated by measure the volume of dielectric in the dielectric sump before and after machining as shown in **Eq. 18.**

$$D_C = \frac{(D_a - D_b)}{t_m \times MRR} \tag{18}$$

where D_a and D_b are the volume of dielectric in the sump (cm^3), before and after machining and t_m is the machining time.

Chapter 5

Optimization using VIKOR

There are four input parameters in this case study which we have to optimize to achieve the green EDM.

- Current
- Pulse duration
- Dielectric level
- Flushing pressure

These are independent variables.

For optimization of these parameters we have to analyze the output responses; process time, relative tool wear ratio, process energy, concentration of aerosol and dielectric consumption.

Process time can be calculated by the **Eq. 15**, relative tool wear is calculated by calculated the ratio of tool wear ratio and material removal rate as shown in **Eq. 16**, process energy is calculated by **Eq. 17**, concentration of aerosol is calculated by **Eq. 12** and dielectric consumption is calculated using **Eq. 18**.

After calculated the output responses, L9 (3^4) orthogonal array is selected to conduct experimental runs. The process variables and their levels for the design used in this study are shown in **Table 1**. The design of experiment matrix and experimental results are presented in **Table 2**.

Table 1 : Input parameters and their levels [22]

Parameters	Unit	Level 1	Level2	Level 3
Current	A	2	4.5	7
Pulse duration	μs	2	261	520
Dielectric level	mm	40	60	80
Flushing pressure	Kg/cm^2	0.3	0.5	0.7

Table 2 : Experimental results [22]

SI. No.	Input parameters				Output parameters				
	Peak current (A)	Pulse duration (µs)	Dielectric level (mm)	Flushing pressure (kg/m^3)	Process time (s)	REWR	Process energy (W)	Conc. of aerosol (mg/m^3)	Dielectric consumption (cm^3)
1	2	2	40	0.3	0.7258	0.3899	54.433	0.82	0.0665
2	2	261	60	0.5	1.5357	0.0055	115.178	0.77	0.0981
3	2	520	80	0.7	1.6393	0.0051	122.951	0.64	0.0865
4	4.5	2	60	0.7	0.4705	0.3496	79.389	1.22	0.0510
5	4.5	261	80	0.3	0.3415	0.0041	57.620	2.13	0.0332
6	4.5	520	40	0.5	0.3942	0.0049	66.516	1.98	0.0394
7	7	2	80	0.5	0.4062	0.3452	106.632	2.4	0.0497
8	7	261	40	0.7	0.2381	0.0065	62.4884	4.12	0.0351
9	7	520	60	0.3	0.2646	0.0076	69.469	5.05	0.0434

5.1 Optimization procedure

First we calculate the normalize matrix, as shown by the **Eq. 19.**

$$\vec{X}_{ij} = \begin{bmatrix} 0.2878 & 0.6214 & 0.2126 & 0.1059 & 0.369 \\ 0.609 & 0.00876 & 0.45 & 0.0995 & 0.545 \\ 0.650 & 0.00812 & 0.4804 & 0.0827 & 0.48 \\ 0.1866 & 0.5572 & 0.3102 & 0.1577 & 0.283 \\ 0.1354 & 0.006535 & 0.225 & 0.275 & 0.184 \\ 0.1563 & 0.00781 & 0.2599 & 0.255 & 0.219 \\ 0.1611 & 0.5502 & 0.4166 & 0.31 & 0.276 \\ 0.0944 & 0.01036 & 0.2441 & 0.532 & 0.195 \\ 0.1049 & 0.0121 & 0.2714 & 0.652 & 0.241 \end{bmatrix} \tag{19}$$

After normalize matrix we will calculate the positive and negative ideal solution for each output response. And in this case study for all output responses positive ideal solution will be minimum value and negative ideal solution will be maximum value from their correspondent column.

For process time

Positive ideal solution = 0.0944

Negative ideal solution = 0.650

For relative tool wear ratio

Positive ideal solution = 0.006535

Negative ideal solution = 0.6214

For process energy

Positive ideal solution = 0.2126

Negative ideal solution = 0.4804

For concentration of aerosol

Positive ideal solution = 0.0827

Negative ideal solution = 0.652

For dielectric consumption

Positive ideal solution = 0.184

Negative ideal solution = 0.545

Then we will calculate utility measure (S_i) and regret measure (R_i);

Utility measure matrix (S_{ij}), shown by the **Eq. 20.**

$$S_{ij} = \begin{bmatrix} 0.0696 & 0.2 & 0 & 0.0082 & 0.1025 \\ 0.1852 & 0.0007 & 0.1773 & 0.0059 & 0.2 \\ 0.2 & 0.0005 & 0.2 & 0 & 0.1639 \\ 0.0332 & 0.1791 & 0.0733 & 0.0263 & 0.0548 \\ 0.0147 & 0 & 0.0093 & 0.0676 & 0 \\ 0.0223 & 0.0004 & 0.0353 & 0.0605 & 0.0194 \\ 0.0240 & 0.1768 & 0.1524 & 0.0799 & 0.0509 \\ 0 & 0.0012 & 0.0235 & 0.1578 & 0.0061 \\ 0.0038 & 0.0018 & 0.0439 & 0.2 & 0.0316 \end{bmatrix} \tag{20}$$

Now Regret Measure will be the maximum value of each row in utility measure matrix.

Both values of Utility measure and Regret measure are shown in the **Table 3.**

Table 3 : Values of utility measure and regret measure

SI. NO.	utility measure (S_i)	regret measure (R_i)
1	0.3803	0.2
2	0.5692	0.2
3	0.5645	0.2
4	0.3668	0.1791
5	0.0916	0.0676
6	0.1379	0.0605
7	0.4840	0.1768
8	0.1887	0.1578
9	0.2811	0.2

After calculating the values of Utility measure and Regret measure, we will find the VIKOR index for Determination of optimal parametric combination. The multi-attribute quality scores for each alternative can be determined from the VIKOR index. The best one is finally determined, in view of the fact that a smaller VIKOR value indicates a better quality. Values of VIKOR index as shown in **Table 4,** for each experimental run.

Table 4 : VIKOR index

SI. NO.	Current (A)	Pulse Duration (μs)	Dielectric Level (mm)	Flushing Pressure (kg/cm^2)	VIKOR INDEX
1	2	2	40	0.3	0.8022
2	2	261	60	0.5	1.0000
3	2	520	80	0.7	0.9951
4	4.5	2	60	0.7	0.7132
5	4.5	261	80	0.3	0.0254
6	4.5	520	40	0.5	0.0484
7	7	2	80	0.5	0.8276
8	7	261	40	0.7	0.4503
9	7	520	60	0.3	0.6984

Chapter 6

Results and discussions

The VIKOR Index for each experiment of the L9 orthogonal array were calculated as discussed in the previous section **Table 4.** According to the performed experiment design, it could be clearly observed from **Table 4**, that the EDM parameters setting of experiment No. 5 yielded the lowest VIKOR index. Therefore, experiment No. 5 had the optimal machining parameters setting for the desirable output responses simultaneously (i.e. the best multi-performance characteristics) among the nine experiments. The response table for the Taguchi method was used to calculate the VIKOR index for each level of the input parameters. The procedure is: (i) group the VIKOR index by factor level for each column in the orthogonal array and (ii) take the average of them.

The VIKOR index values for each level of process parameters are shown in **Table 5**. Regardless of the category of performance characteristics, a lower VIKOR index value corresponds to better performance. Therefore, the optimal level of the machining parameters was the level with the lowest VIKOR index value. Based on the VIKOR index values given in **Table 5**, the optimal machining performance for the green EDM is obtained for 4.5A peak current (level 2), 261 μs pulse duration (level 2), 40 mm dielectric level (level 1) and 0.3 kg/cm^2 flushing pressure (level 1). As listed in **Table 5**, the difference between the maximum and the minimum value of the VIKOR index of the EDM parameters are as follow: 0.6701 for peak current, 0.2891 for pulse duration, 0.3702 for dielectric level and 0.2109 for flushing pressure. The most effective factor affecting performance characteristics was determined by comparing these values. This comparison demonstrated the level of significance of the input parameters over the multi-performance characteristics. The most effective controllable factor will be the maximum of these values. Here, the maximum value is 0.6701. This value indicated that the **peak current** had the strongest effect on the multi-performance characteristics among the input parameters. The order of importance of the controllable factors to the multi-performance characteristics in the EDM process, in sequence can be listed as follows: peak current, dielectric level, pulse duration and flushing pressure, as shown in response **Table 5** for VIKOR index.

Table 5 : Computed means of VIKOR index

Input parameter	Average VIKOR INDEX			Max–min	Rank
	Level 1	Level 2	Level 3		
Peak current	0.9324	0.2623	0.6588	0.6701	1
Pulse duration	0.7810	0.4919	0.5806	0.2891	3
Dielectric level	0.4336	0.8039	0.6160	0.3702	2
Flushing pressure	0.5087	0.6253	0.7195	0.2109	4

Taguchi method is used to plot means for VIKOR index for each level of input parameters. It can be clearly observed from the **Figure 3,** that for optimal machining parameter for green EDM are 4.5 A peak current, 261 μs pulse duration, 40 mm dielectric level and 0.3 kg/cm^2 flushing pressure.

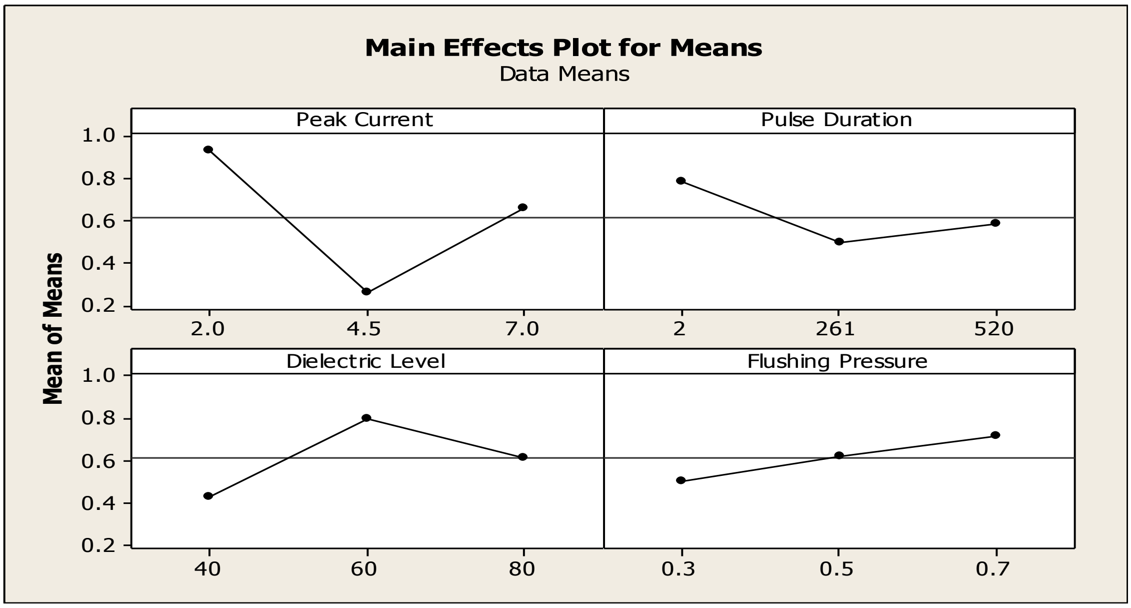

Figure 3 : Means plot for VIKOR index

Taguchi method is also used to compute the S/N (signal to noise) ratio of VIKOR index for each level of input parameters as shown in **Table 6,** and S/N ratio plot for VIKOR index as shown in **Figure 4.**

Table 6 : Computed S/N ratio of VIKOR index

Input parameter				Max–min	Rank
	Level 1	Level 2	Level 3		
Peak current	0.6523	20.3807	3.8972	19.7284	1
Pulse duration	2.1646	12.9444	9.8212	10.7799	2
Dielectric level	11.7158	2.0179	11.1965	9.6976	3
Flushing pressure	12.3119	9.3156	3.3028	9.0091	4

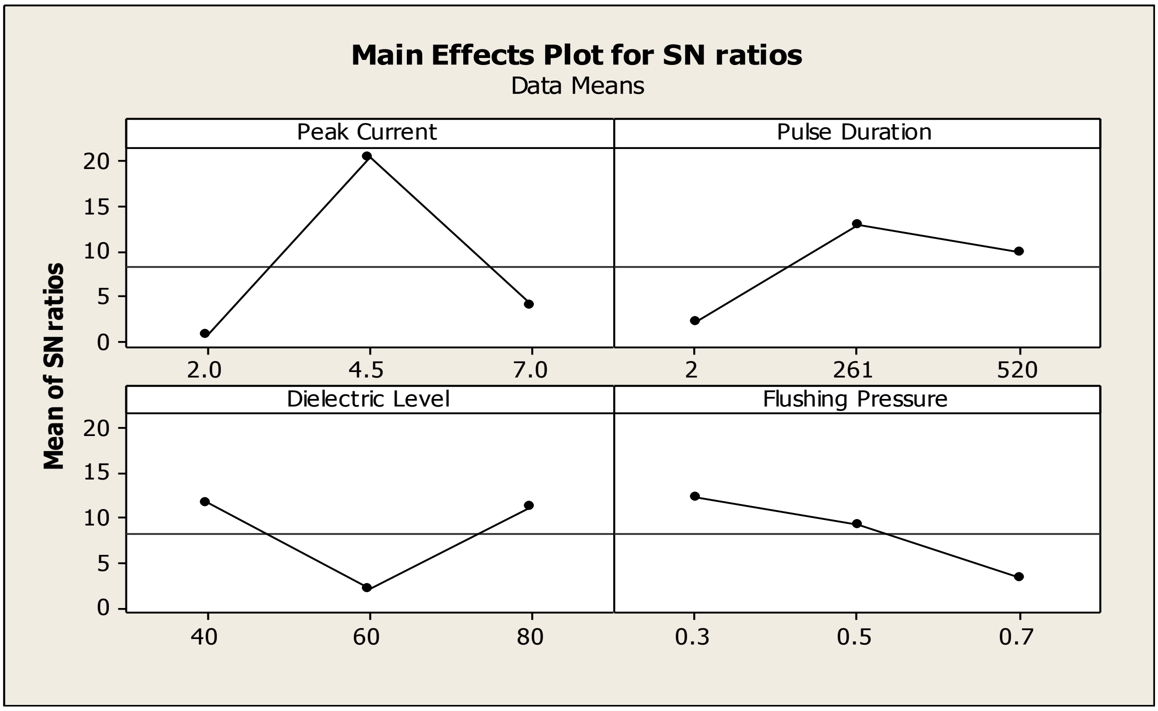

Figure 4 : S/N ratio plot for VIKOR index

If this problem (multi-response parameter optimization problem in green electro-discharge machining) evaluated by combination of Taguchi method and TOPSIS then, the optimum factor level combinations were identified based on the closeness coefficient values. The optimal machining performance for the green EDM was obtained for 4.5 A peak current (level 2), 261 μs pulse duration (level 2), 40 mm dielectric level (level 1) and 0.5 kg/cm^2 flushing pressure (level 2). From analysis of the closeness coefficients, it was identified that the peak current was the most influential parameter in multi-performance characteristics. And by solving the same problem using combination of Taguchi and VIKOR method the results are different, as using TOPSIS the optimal value of flushing pressure was 0.5 kg/cm^2, while in VIKOR the optimal value of flushing pressure is 0.3 cm^2, while other optimal values are same for both methods. And by solving the same problem from both methods peak current had the strongest effect on the multi-performance characteristics among the input parameters.

Conclusions

In the present study, application feasibility of a MCDM approach: VIKOR method has been highlighted to solve multi-criteria decision making problems through a case study of green EDM. The study demonstrates the effectiveness of the said MCDM techniques in solving such a conflicting criteria problem. The present work proposed a combination of Taguchi method and VIKOR to solve the multi-response parameter optimization problem in green electro-discharge machining. An analytical structure has been developed to perform multi-criteria decision making. The responses were ranked based on the scores obtained by the summarization of final preference weights. The optimum factor level combinations were identified based on the VIKOR index values. The optimal machining performance for the green EDM was obtained for 4.5 A peak current (level 2), 261 μs pulse duration (level 2), 40 mm dielectric level (level 1) and 0.3 kg/cm^2 flushing pressure (level 1). From analysis of the VIKOR index, it was identified that the peak current is the most influential parameter in multi-performance characteristics used in this study. The computational and experimental effort needed to optimize these parameters was rather small. It is illustrated that the method is efficient and effective for multi-attribute decision making problems in green manufacturing.

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