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Optimization of Green Electro-Chemical Machining Using Multi Criteria Decision Making Tools VIKOR

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***Abstract*— In the present scenario an proficient Multi-Criteria Decision Making (MCDM) approach has been predictable for optimization of green electro-chemical machining, because it is a commonly used non-traditional machining process. Electrochemical machining (ECM) has predictable itself as one of the major alternatives to conventional methods for machining hard materials and versatile contours deficient the residual stresses and tool wear. ECM has spacious-ranging purpose in automotive, petroleum, aerospace, textile industries, medical fields, electronic industries etc. The optimization of Green electro-chemical machining is a Multi-Criteria Decision Making (MCDM) problem narrow-minded by several performance criteria and alternatives. These criteria's and alternatives are commonly two types, qualitative and quantitative. These problems are analyzed and identified using many MCDM tools and techniques So to find the best alternative solution of MCDM problems there should be transformed quantitative criteria values into an equivalent single performance index called Multi-attribute Performance Index (MAPI). In this text, present study highlights application of VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) that means: Multicriteria Optimization and Compromise Solution. This Method personalized from MCDM techniques for obtaining the precise result. Detailed methodology of VIKOR method has been described in this paper through a case study.**

***Keywords*— Multi Criteria Decision Making (MCDM), Green Electro Chemical Machining, Multi-attribute Performance Index (MAPI), VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)..**

I. INTRODUCTION

Decision making is the practice used in upstream of both industries and academia resulting in the selection of a best suitable course of action among a set of alternative with respect to set of criteria's in this study. The decision making process is identifying and selecting best alternatives with respect to criteria based on the values and preferences of the decision makers as well as experts opinion. On the basis of unambiguous assumptions analysis of the individual decision is concerned with the logic of decision making which can be rational or irrational. The set of logical decision making is an important part of all science based professions, where experts used their knowledge in a given area to make the good decisions which can be use for to make best result.

In India all the manufacturing industries, manufacturing work as spine for the manufacturing of raw material. Its consequence can be calculated by the fact that, in an economic activity, it comprises nearly 30 to 35% of the value of all finished goods and services produced in the manufacturing organization. The optimum level of manufacturing activity of a India is directly pertaining to its economic strength. So we can easily say that the optimum level of manufacturing activity in any country will be rise day to day, the level of people has standard and the living position will be high. Manufacturing of a material can be defined as the converting of raw material with the process of physical, mechanical and chemical processes in different stages to modify the geometrical properties of a given material in the making of finished goods. The change of raw material to finished goods with efforts includes all intermediate processes required for the production and incorporation of components. The capability to produce finished from this conversion process of raw material to final product which can be easily determines the success of the any manufacturing organization. The type of manufacturing performed by organization depends on the types of products it manufactured by the industry. Manufacturing is an imperative profitable activity carried out by organization that put on the market final products to their customers. In the present scenario, manufacturing process involves consistent activities that include material selection, product design and developments, process planning, production, quality assurance, documentation, management, and marketing of products and services.

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II. LITERATURE REVIEW

Tong et al. (2007) presented VIKOR method, ranking for multicriteria decision making (MCDM) tools, towards optimizing the multiple response process. This technique author considered to assure small variation in quality loss mean and the standard variation with several multiple responses along with a small overall average loss. Khuri and Conlon (1981) obtained polynomial regression model for the optimizing various responses related to best alternatives selection. In this model author used tools and techniques for optimizing the best solution among given alternatives. In this study they defined a distance function with considering the ideal solution for the determine g the best condition with minimizing the process function. Anisseh et al. (2012) proposed a methodology for fuzzy approach towards extension of TOPSIS method for heterogeneous group decision making models under fuzzy environment which converts the decision maker's fuzzy decision matrices into an aggregated decision matrix to establish the best preferable choice amongst all possible choices. Shao et al. (2006) obtained a novel approach for the dilemma, where collaboration and reliability are introduced for aggregating the experts' judgments. Moreover, a fuzzy numerous alternatives group decision-making specialist systems are planned to provide an interactive way to make clear complex things in mutual atmosphere. It is an intelligent integrated system because it combines fuzzy set theory with the technique of group opinion aggregation. Kuo et al. (2006) presented an pioneering way, namely green fuzzy design analysis (GFDA), which occupies simple and proficient procedures to appraise product design substitutes based on ecological deliberation with fuzzy logic. The hierarchical arrangements of environmentally conscious intend indices was created with the analytical hierarchy process (AHP). Subsequent to weighting factors for the ecological attributes are determined, the most suitable design alternative can be preferred based on the fuzzy multi-attribute decision making (FMADM) tools and technique. The profit of using such a methodology is to inefficiently resolve the design difficulty by capturing human expertise. And also offered an efficient green fuzzy analysis methodology to permit designers evaluates unusual design alternatives and come up with an environmentally benign product design. Lai et al. (2002) presented the report of results of a case study where the AHP technique was employed to support the selection of a multi-media authorizing system (MAS) for the solving of problem related in a group decision environment. The experiment with results and survey findings indicated that the AHP techniques is suitable compare to Delphi, it helps group members centre a discussion upon objectives, rather than alternatives. Opricovic and Tzeng (2007) presented the VIKOR method to solve MCDM related problems considering with conflicting and non commensurable criteria. It assuming that compromising solution is adequate for conflict resolution. This method generally focuses on ranking and selecting the best from a set of alternatives. This method developed with a stability analysis determining the weight stability intervals. In this paper the developed VIKOR method is compared with three MCDM methods: TOPSIS, PROMETHEE, and ELECTRE. Swarnakar and Vinodh (2015) introduced four improvement alternatives in the context of Six Sigma are considered with twelve governing criteria. The formulated decision making problem is solved using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Based on expert input, computations are performed and alternatives are ranked. Vinodh and Swarnakar (2015) introduced Lean Six Sigma (LSS) project selection has been formulated as the Multi Criteria Decision Making (MCDMO tools with problem. Hybrid MCDM method based on Decision-Making Trial and Evaluation Laboratory Model (DEMATEL), Analytical Network Process (ANP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) has been used to select the optimal LSS project. The methodology enabled the practitioners to systematically prioritize LSS projects. Swarnakar and Vinodh (2015) introduced LSS is a business process improvement strategy widely used in the manufacturing field for enhancing manufacturing organization performance. The integration of Lean and Six Sigma will enable the attainment of defects reduction by eliminating non-value-adding activities from production line. LSS framework has been developed with the integration of define– measure–analysis–improve -control (DMAIC) tools and techniques. Shemshadi et al. (2011) developed VIKOR methodology to solve multiple criteria decision making (MCDM) problems with conflicting and non-commensurable criteria. In this paper they have taken objective weights based on Shannon entropy concept or even taking into account the end-users' opinions.

III. METHODOLOGY

The past origins of Multi Attribute Decision Making (MADM) can be traced back to correspondence between Nicolous Bernoulli (1687-

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1759) and Pierre Remond de Montmort (1678-1719), denotes the MADM related problem and solving with this techniques. A game is played by tossing a fair coin until it comes up tails and the total number of flips, n, determines the winner, which equals \$2×n If the coin comes up heads the first time, it is tossing again, and then the same case occurs then 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 behavior since no one is willing to pay more than 1000 \$ for this game. We ignore the concrete discussions 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 [12]. Systematically approaching these types of problems is solved by a general process called multi-attribute decision analysis (MADA).

IV. ELECTRO CHEMICAL MACHINING

Electrochemical machining (ECM) is one of the imperative non-traditional machining process for machining hard conductive materials which are difficult to cut, high strength and heat resistant materials into complex shape. ECM can cut small or odd-shaped angles, intricate contours or cavities in hard and exotic metals, such as Titanium aluminides , Inconel, Waspaloy , and high Nickel, Cobalt, and Rhenium alloys. Both external and internal geometries can be machined. Electrical current passes through an electrolyte solution between a cathode (tool) and an anode (workpiece). The workpiece is eroded in accordance with Faraday's law of electrolysis. In today's' competitive Manufacturing sector, Electro Chemical Machining (ECM) process has become a major concern for every industry. Electrochemical machining (ECM) has established itself as one of the major alternatives to conventional methods for machining hard materials and complex contours without the residual stresses and tool wear. Electrochemical machining (ECM) was developed to machine difficult-to cut materials, and it is an anodic dissolution process based on the phenomenon of electrolysis, whose laws were established through Michael Faraday [13]. The principle of ECM is shown in figure 1.

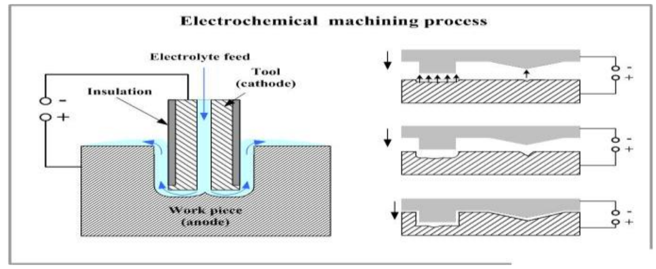


Fig. 1: Principle of Electrochemical Machining

V.COMPUTATIONAL STEPS AND DECISION MAKING MODEL OF GREEN ECM

1.Decision making model for green ECM

Decision making model consists of the following two types of attributes.

- Manufacturing
- Environmental

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

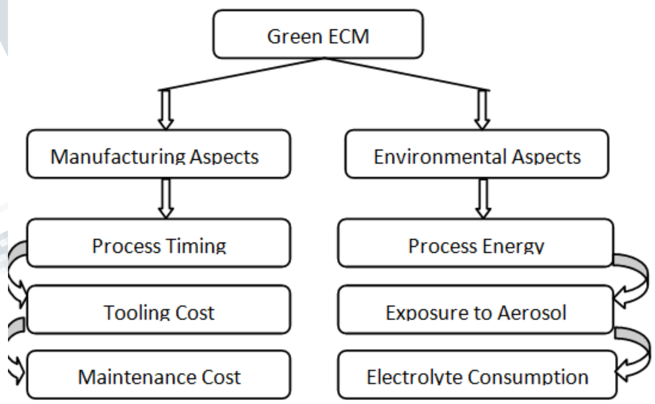
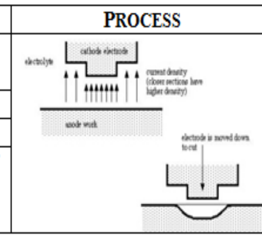


Figure 2: Decision making model for green ECM

2. Input-process-output diagram of ECM process

In a input-process output model as shown in Table 1 shows the relationship between the process parameters and output responses.

Table 1: input-process output model

INPUT	PROCESS	OUTPUT
FEED RATE		MATERIAL REMOVAL RATE
VOLTAGE		ACCURACY
ELECTROLYTE		SURFACE FINISH
NATURE OF POWER SUPPLY		PROCESS ENERGY
		TOOLING COST
		PROCESSING TIME

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3.Computational Steps for Prioritizing Green ECM

Step 1: Representation of normalized decision matrix

The normalized decision matrix can be expressed as follows:

$$F = (f_{ij})_{m\times n} \qquad \text{(i)}$$

Here, $(f_{ij}) = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} x^2{}_{ij}}}$, i = 1,2…..,m; and X_{ij} is the performance of alternative A_i with respect to the j_{th} criterion

Step 2: Determination of ideal and negative-ideal solutions

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

$$A^* = \{(\max f_{ij} \mid j \in J) \text{or} \{(\min f_{ij} \mid j \in J'), i = 1,2,\ldots\ldots m\} = \{f_1^*, f_2^*, \ldots\ldots f_j^*, \ldots\ldots f_n^*\} \qquad \text{(ii)}$$

$$A^- = \{(\min f_{ij} \mid j \in J) \text{or} \{(\max f_{ij} \mid j \in J'), i = 1,2,\ldots\ldots m\} = \{f_1^-, f_2^-, \ldots\ldots f_j^-, \ldots\ldots f_n^-\} \qquad \text{(iii)}$$

Where J = {j = 1,2,…..n | f_{ij}, if desire respose is large}
J' = {j = 1,2,…..n | f_{ij}, if desire respose is small}

Step 3: Calculation of utility measure and regret measure

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

$$S_i = \sum_{j=1}^{n} w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \qquad \text{(iv)}$$

$$R_i = \max_j \left[w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)}\right] \qquad \text{(v)}$$

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:

$$Q_i = \upsilon\left[\frac{S_i - S^*}{S^- - S^*j}\right] + (1-\upsilon)\left[\frac{S_i - S^*}{S^- - S^*j}\right] \qquad \text{(vi)}$$

where, Q_i , represents the *ith* alternative VIKOR value, *i* =1, 2,........,*m*; S^* = min i (Si), S^- = max i (Si), R^* = min i (Ri), R^- = max i (Ri), and υ is the weight of the maximum group utility (usually it is to be set to 0.5. The alternative having smallest VIKOR value is determined to be the best solution. There are four input parameters in this case study which we have to optimize to achieve the green ECM.

- Feed Rate
- Voltage
- Electrolyte
- Nature of power supply

These are independent variables. The data are collected from manufacturing industry and responses are calculated using formula. The process variables and their levels for the design used in this study are shown in Table 2. The design of experiment matrix and experimental results are presented in Table 3.

Table 2 : Input parameters and their levels

Parameters	Round 1	Round 2	Round 3	Round 4	Round 5
Feed Rate	2.0	1.9	1.9	2.0	1.8
Voltage	110	111	112	113	114
Electrolyte	50	55	60	65	70
Nature of Power supply	210	210	220	220	220

Table 3 : Experimental results

S. NO.	Feed Rate (IPR)	Voltage (Volt)	Electrolyte consumption (MM)	Power Supply (Watt)	MRR (MIN)	Accuracy(Scale)	Surface Finish (H)	Process Energy (W)	Tooling cost (Rs.)	Processing time (S)
1	2.0	110	50	210	0.0278	1.9999	54	58.123	4000	2158
2	1.9	111	55	210	0.0556	1.8888	58	60.344	4200	1079
3	1.9	112	60	220	0.0833	1.7777	60	70.345	4500	720
4	2.0	114	65	220	0.1111	1.6666	65	80.116	5000	540
5	1.8	115	70	220	0.1389	1.5555	70	96.966	5200	432
6	2.0	110	50	210	0.0278	1.9999	54	58.123	4000	2158
7	1.9	111	55	210	0.0556	1.8888	58	60.344	4200	1079
8	1.9	112	60	220	0.0833	1.7777	60	70.345	4500	720
9	2.0	113	65	220	0.1111	1.6666	65	80.116	5000	540
10	1.8	114	70	220	0.1389	1.5555	70	96.966	5200	432

4. Optimization procedure

First we calculate the normalize matrix "Xij", as shown in the Eq. (i).

0.8123	0.7569	0.7856	0.2569	0.3251	0.7854
0.5658	0.6532	0.8695	0.2546	0.8694	0.5648
0.2356	0.1589	0.6894	0.3254	0.7568	0.2579
0.5986	0.4565	0.6359	0.2869	0.3652	0.3349
0.5656	0.2569	0.3569	0.4568	0.2568	0.2587
0.8965	0.2564	0.3969	0.2584	0.1456	0.6598
0.2568	0.5869	0.7856	0.5986	0.2541	0.4586
0.2687	0.5623	0.6983	0.9548	0.1452	0.2658
0.3549	0.3254	0.6984	0.7845	0.8965	0.5896
0.3459	0.5869	0.3216	0.3254	0.8652	0.8956

For MRR process time

Positive ideal solution = 0.2356, Negative ideal solution = 0.8965

For Accuracy

Positive ideal solution = 0.1589, Negative ideal solution = 0.7569

For Surface finish operation

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Positive ideal solution = 0.3216, Negative ideal solution = 0.8695

For Process Energy
Positive ideal solution = 0.2546, Negative ideal solution = 0.9548
For tooling cost
Positive ideal solution = 0.1452**,** Negative ideal solution = 0.8965
For processing time
Positive ideal solution = 0.2579, Negative ideal solution = 0.8956
Then we will calculate utility measure (Si) and regret measure (Ri); Utility measure matrix (Sij), shown in the Eq. (iv) and (v).

0.0965	0.1	0	0.1	0.0154	0.1534
0.2568	0.0325	0.2354	0.0235	0.1546	0.1
0.1	0.0096	0.1	0.0864	0	0.0356
0.0235	0.1458	0.1256	0.0124	0.0125	0.0125
0.0569	0	0.0156	0.0965	0.0236	0
0.0856	0.0156	0.0958	0.0234	0.0236	0.1258
0.0159	0.0235	0.2568	0	0.0365	0.0987
0	0.2365	0.1589	0.2789	0.0145	0.0569
0.3549	0.1253	0.1287	0.1256	0.1569	0.1235
0.1206	0.1289	0.0568	0.0231	0.1	0.2369

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 4

Table 4 : Values of utility measure and regret measure

S.No.	Utility measure (Si)	Regret measure (Ri)
1	0.3256	0.1543
2	0.2698	0.2568
3	0.8965	0.1
4	0.2145	0.1458
5	0.1869	0.0965
6	0.5647	0.1258
7	0.8963	0.2568
8	0.4986	0.2789
9	0.7546	0.3549
10	0.2389	0.2369

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 5, for each experimental run.

Table 5 : VIKOR Index

S.No.	Feed Rate (IPR)	Voltage (Volt)	Electrolyte consumption (MM)	Power Supply (Watt)	VIKOR Index
1	1.6	110	50	210	0.8956
2	1.6	111	55	215	0.6523
3	1.7	112	60	220	0.5896
4	1.7	114	65	225	0.2146
5	1.8	115	70	230	0.6584
6	1.8	110	50	210	0.8745
7	1.9	111	55	215	0.2541
8	1.9	112	60	220	0.1587
9	2.0	113	65	225	0.2589
10	2.0	114	70	230	0.8569

The VIKOR Index for each and every experimentation of the L9 orthogonal array were considered as discussed in the earlier division Table 6. According to the performed experimentation design, it could be clearly observed from Table 6, The VIKOR index values for each level of process parameters are shown in Table 7. 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 ECM are 1.8 feed rate, 115watt Voltage, 55 mm Electrolyte Consumption and 230 watt Power Supply.

Table 6 : Computed means of VIKOR index

S.No.	Input parameters	Average VIKOR index					Max-Min	Rank
		Level 1	Level 2	Level 3	Level 4	Level 5		
1	Feed Rate	0.9653	0.7854	0.4145	0.7445	0.8851	0.5508	1
2	Voltage	0.8653	0.6523	0.7854	0.6489	0.4953	0.37	3
3	Electrolyte consumption	0.7856	0.4896	0.5761	0.6856	0.8423	0.3527	4
4	Power Supply	0.5236	0.9423	0.5689	0.7854	0.3956	0.5467	2

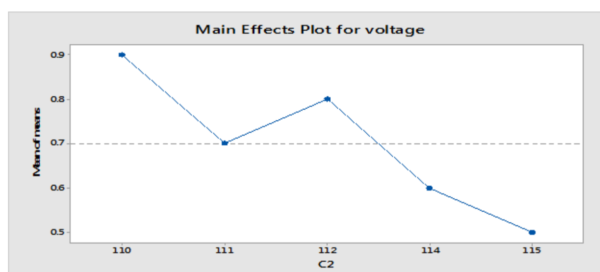

Figure 3 (i) : Means plot for VIKOR

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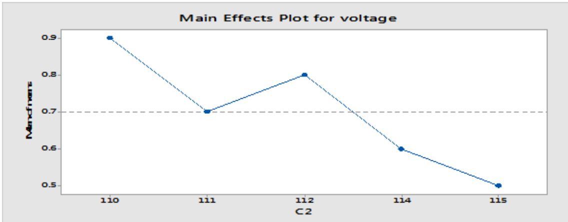

Figure 3 (ii): Means plot for VIKOR index

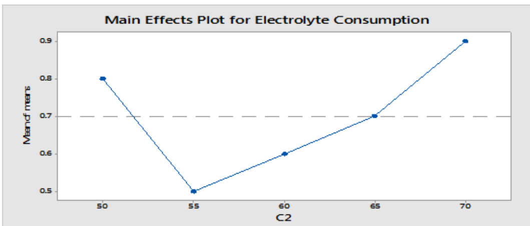

Figure 3 (iii) : Means plot for VIKOR index

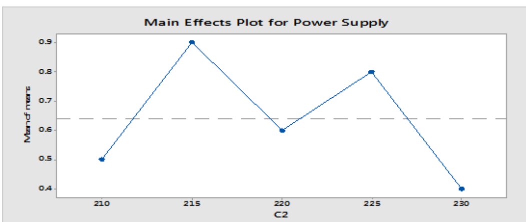

Figure 3 (iv): Means plot for VIKOR index

The VIKOR index values for each level of process parameters are shown in Table 7 and according to that index values draw 4 figure using MINITAB software and shown in figure 3 (i), (ii), (iii), (iv) respectively**.**

Table 7 : Computed S/N ratio of VIKOR index

S.N o.	Input Parameters	Average VIKOR Index					Max-Min	Rank
		Level 1	Level 2	Level 3	Level 4	Level 5		
1	Feed Rate	10.963	12.785	19.258	9.325	4.325	14.933	1
2	Voltage	12.258	16.652	7.357	8.234	19.325	11.968	3
3	Electrolyte consumption	11.359	14.365	8.365	9.356	3.254	11.111	4
4	Power Supply	15.956	17.365	11.325	5.625	19.254	13.629	2

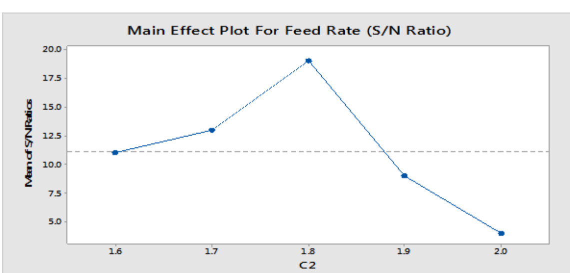

Figure 4 (i): S/N ratio plot for VIKOR index

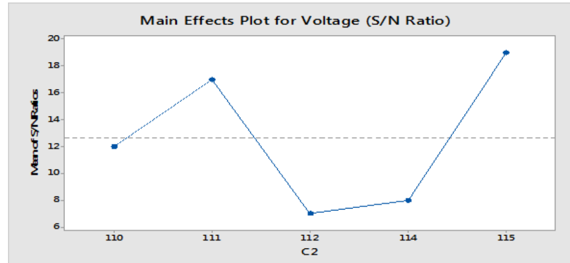

Figure 4 (ii): S/N ratio plot for VIKOR index

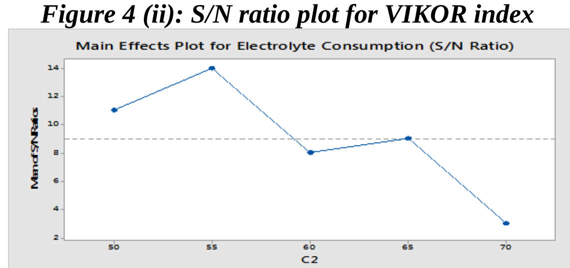

Figure 4 (iii): S/N ratio plot for VIKOR index

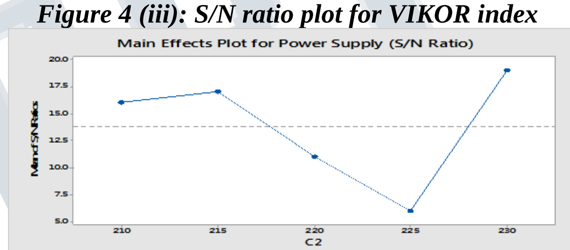

Figure 4 (iv): S/N ratio plot for VIKOR index

The best possible machining performance for the green Electro Chemical Machining was obtained for 1.8 feed rate (level 3), Voltage (level 5), 55 mm Electrolyte Consumption (level 2) and 230 watt Power Supply (level 5). From investigation of the convenience coefficients, it was found that the Feed Rate was the most significant constraint in this case study. We had tried to solve the same problem by using combination of Taguchi and VIKOR method and found that the results are different, as using TOPSIS methodology the optimal value of Power Supply was 240 volt, while in VIKOR the optimal value of Power Supply is 230 volt, while other optimal values are same for both methods. And by solving the same problem from both methods Feed Rate had the strongest effect on the multi-performance characteristics among the input parameters.

VI. CONCLUSION

In the current study, application possibility of a Multi Criteria Decision Making come within reach of: VIKOR method has been highlighted to get to

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the bottom of MCDM problems through a case study of green Electro Chemical Machining. The learning demonstrates the effectiveness of the said MCDM techniques in solving such a conflicting criteria problem. The current work proposed a amalgamation of Taguchi method and VIKOR to explain the multi-response parameter optimization problem in green ECM. An analytical formation has been urbanized to execute multicriteria decision making. The responses were ranked based on the scores obtained by the calculation using VIKOR methodology and summarization of final preference weights. The best possible factor level combinations were identified with the VIKOR index values. The optimal machining performance for the green ECM was obtained for 1.8 feed rate (level 3), Voltage (level 5), 55 mm Electrolyte Consumption (level 2) and 230 watt Power Supply (level 5). From analysis of the VIKOR index, it was identified that the Feed Rate is the most prominent parameter in multi-performance characteristics used in this case 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.

REFERENCES

[1] Tong, L. I., Chen, C. C. and Wang, C. H. (2007), Optimization of multi-response processes using the VIKOR method, International journal of advanced manufacturing technology, Vol. 31, pp. 1049-1057.

[2] Khuri, A. I. and Conlon, M. (1981), Simultaneous optimization of multiple responses represented by polynomial regression functions, American statistical association and american society for quality, Vol. 23, pp. 367-35.

[3] Anisseh, M., Piri, F., Shahraki, M. R. and Agamohamadi, F. (2012), Fuzzy extension of TOPSIS model for group decision making under multiple criteria, Artificial intelligence review, Vol. 38, pp. 325-338.

[4] Shao, X., Zhang, L., Gao, L. and Chen, R. (2006), Fuzzy multiple attributive group decision-making for conflict resolution in collaborative design, Fuzzy systems and knowledge discovery, Vol. 4223, pp. 990-999.

[5] Kuo, T. C., Chang, S. H., and Huang, S. H. (2006), Environmentally conscious design by using fuzzy multi attribute decision making, International Journal of Advanced Manufacturing Technology, Vol. 29, pp. 419–425.

[6] Lai, V. S., Wong, B. K. and Cheung, W. (2002), Group decision making in a multiple criteria environment: A case using the AHP in software selection, European journal of operational research, Vol. 137, pp. 134–144.

[7] Opricovic, S. and Tzeng, G. H. (2007), Extended VIKOR method in comparison with outranking methods, European journal of operational research, Vol. 178, pp. 514 529.

[8] Vinodh, S., & Swarnakar, V. (2015). Lean Six Sigma project selection using hybrid approach based on fuzzy DEMATEL–ANP–TOPSIS. International Journal of Lean Six Sigma, 6(4), 313-338.

[9] Swarnakar, V., Swarnakar, V., Vinodh, S., & Vinodh, S. (2016). Deploying Lean Six Sigma framework in an automotive component manufacturing organization. International Journal of Lean Six Sigma, 7(3), 267-293.

[10] Swarnakar and vinodh (2014) " Lean Six Sigma Project Selection using Analytical Network Process" International Conference on Production And Operetion Management, Proceedings of SOM 2014 December 12-14, Department of Management Studies, IIT Roorkee, pp.805-811.

[11] Shamshadi A., Shirazi, H., Toreihi, M. and Tarokh, M. J. (2011), A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting, Expert systems with applications, Vol. 38, pp. 12160-12167.

[12] Tzeng, G.H. and Huang, J. J. (2012), Multiple attribute decision making: Methods and applications, Chapman and Hall, U.S.

[13] J.A. McGeough, Principle of Electrochemical Machining, Chapman and Hall, London, 1974.