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Analyzing the Effect of Machining Parameters in EDM for Controlling Electrode Wear Rate (EWR): A Critical Study for Sustainable Production

Nitin Kumar Sahu[1*], Mukesh Kumar Singh[2], Atul Kumar Sahu[3]

[*1,2 3]Department of Industrial and Production Engineering, Guru Ghasidas (Central) Vishwavidyalaya,

Bilaspur - 495009, Chhattisgarh, India

[*]Communicating Author (Email: nitin83sahu@gmail.com)

Abstract: Electrical discharge machining (EDM), also known as spark machining, spark eroding and die sinking machining process, is a metal removal process where desired shape can be obtained by using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, which is separated by a dielectric liquid and subject to an electric voltage. EDM is one of the efficient machining processes for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. Inconel 825 is a family of austenite Nickel-Chromium based super alloys and having wide application in numerous engineering fields. The presented study provides a valuable insight for the selection of the process parameters setting in Electrical Discharge Machine (EDM) in order to minimize electrode wear ratio (EWR) by using copper electrode materials. It is found that optimal process parameters setting is $Ton_1Toff_1Vg_2Sg_1$ for minimizing EWR. The results clearly depict that the combination of independent process parameters i.e. Ton, Toff, Vg and Sg is found as 100, 20, 60 and 005 for optimizing EWR

Keywords: Electrical Discharge Machining (EDM); Taguchi Technique; Orthogonal Array (OA); Electrode Wear Rate (EWR).

1. INTRODUCTION

EDM is a most widely acceptable machining process and comes in the category of non conventional machining process. It removes metal from the workpiece by employing thermal energy to machine electrically conductive parts regardless of hardness. It is specifically employed in machining of mould, die, automotive, aerospace, surgical components etc. Here, the voltage is applied in between the tool and the electrode. Here, there is no direct contact in between the tool and work piece. When there is increase in the voltage between the electrode and the workpiece, the intensity of the electric field increases, causing dielectric break down, and produces an electric spark, which results in material removal from the workpiece. Once the current stops (or is stopped, depending on the type of generator), new liquid dielectric is conveyed into the inter-electrode volume, enabling the solid particles (debris) to be carried away and the insulating properties of the dielectric to be restored. Adding new liquid dielectric in the inter-electrode volume is commonly referred to as flushing. After a current flow, the voltage between the electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur to repeat the cycle.

2. STATE OF ART

Many researchers have tried to optimize the various important process characteristics of EDM in different domain. Kansal et al. (2007) studied the effect of mixing of silicon powder in the dielectric and its impact on the Material removal rate (MRR) of AISI D2 Die Steel material and found that Peak current, concentration of the silicon powder, pulse-on time and pulse-off time have influential affect on the MRR in PMEDM. It is also found that the peak current and concentration of silicon powder are the most influential parameters for maximizing material removal and the nozzle flushing, when applied at the interface of tool electrode and work piece, does not significantly affect the MRR. Marafona and Wykes (2000) utilized two-stage processing method to improve material removal rate for a given tool wear ratio. Chena et al. (2007) utilized TiNiCr and TiNiZr ternary shape memory alloys and found that the roughness of EDMed surface increases with the discharge current and pulse duration. Singh et al. (2004) utilized Al-10%SiC

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composites material in order to optimize process variable and their impact on the output responses via employing grey relational analysis in EDM. Iqbal and Khan (2010) employed a Central Composite Design (CCD) for combination of variables and used Response Surface Method (RSM) to analyze the performance of EDM process. Petropoulos et al. (2004) employed statistical modeling approach and copper & graphite tools are used as electrodes, for identifying the impact of process parameters on surface finish. Various researchers are continuously examining and working to develop a tool material that will significantly improves the characteristics of EDM output responses. In present investigation the authors have tried to attempt the effect of various crucial process parameters in EDM in order to minimize the EWR. The materials selected for the present study is Inconel 825 due to its widest application in crucial engineering applications.

3. SUSTAINABILITY AND MANUFACTURING

Sustainability endeavours economical advantages and thus it is significant to investigate sustainable manufacturing initiatives. The same is necessary for retaining green manufacturing and yielding elevated outputs. Sustainable manufacturing is the production of manufactured goods by the course of economically sound process with the aim to minimize the negative environmental impacts. Today it is required to develop decision making framework and tools for precise manufacturing and industrial applications (Sahu et al., 2017a; Sahu et al., 2017b). It is significant to determine the crucial machining characteristics and optimum setting for extracting elevated outputs from group of inputs (Chaturvedi et al., 2018; Sahu et al., 2018a). Sustainability attempts to retrieve conservation of energy and natural resources. Sustainable manufacturing and consumption deal with doing more and better with less exploitation of natural resources. Energy consumption and environmental impact, while doing manufacturing is now been considering by the researchers as an important field of interest and thus researchers are now seeking performance drivers and optimized setting for the sustainable manufacturing. It is profitable to appraise multiple outputs for assuming effectiveness and efficacy from implicated resources (Wang et al., 2019; Sahu et al., 2019). Additionally, it is fruitful to evaluate multiple outputs for assuming effectiveness and efficacy from implicated resources (He et al., 2021; Sahu et al., 2018b). Nowadays it is required to process smart alloys having high strength to satisfy the societal needs and thus electrical discharge machining (EDM) machining process is found as an alternative means, but there needs to determine the effect of Machining Parameters in EDM for evaluating output parameters. The study presents sustainable manufacturing practices, which chiefly concentrated to improve the output characteristics with the intention to reduce energy consumption and environmental loads. The study disclosed that the experiments conducted needs to be properly designed based on machine levels to acquire the effects of the main process parameters on the electrode wear rate (EWR) and Material Removal Rate (MRR). Thus, significant driving characteristics should be identified for extracting elevated outputs from group of inputs (Kang et al., 2022; Sahu et al., 2020). The same is required to help in the attainment of less consumption of resources and to analyze the information receiving from the customers and operators (Sahu et al., 2014; Sahu et al., 2015). But a decision making process is required, which possess series of steps to determine the best option or course of action to meet the needs of the society (Guo et al., 2022; Sahu et al., 2022). It is demonstrated in present study, that EDM posse's significant advantages and potential for the manufacturing applications of smart alloys in the field of sustainable manufacturing.

4. RATIONALIZATION AND OPTIMIZATIONS

Today, hybrid materials are the demand of the society and that needs to be processed by the manufacturing resources under sustainable aspects. The same is nowadays are in the high interest of the researchers and industries and is holding an application of producing near net shape metal components and precise manufacturing for assembly purpose. The smart materials have strengthening properties like high thermal conductivity, superior wear resistance properties, high corrosion resistance etc., which makes their elevated applicability in the industrial realm of aerospace, automotive, radiators, tool manufacture, robots design, hazardous works, radioactive means, biomedical industry etc., These material can be machined with electrical discharge machining (EDM), but that needs the proper selection and attention of process parameters to attain outputs parameters. The machining in EDM needs to be properly evaluated from the insights of control variable and uncontrolled variables by generating a decision making model, which can accurately correlate the input parameters of EDM with the responses because the parameters setting are restricted with the operator's experience. The EDM machine possess a bunch of process parameters like pulse-on time, pulse-off time, peak current and voltage, which needs to be synchronized for attaining appropriate setting. The same can be attained by utilizing Design of experiment (DOE). The analysis is required after DOE to determine effect of the surface characteristics based on hardness of work material. It is found that the elevated levels of output can be attained by the final result of optimization of process parameters. The present study highlights the influence of detecting important process parameters to be considered by manufacturing materials by EDM.

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5. EXPERIMENTATION PROCEDURE AND DATA COLLECTION
6.

In current investigation, the authors are trying to investigate the effect of various process parameters on electrode wear ratio (EWR) on Inconel 825 material. The machining process is carried out by employing kerosene as a dielectric fluid which creates path for discharge. The workpiece is connected to the positive terminal and the tool electrode is connected across the negative terminal. The reason behind using these polarities is that approximately two third of the total heat generated is generated across the positive terminal i.e. workpiece. First, both the work piece as well as tool is submerged into dielectric fluid. The dielectric fluid help to control the arc discharge and removes suspended particles of work piece material and tool from the work cavity. Proper arc gap is maintained by the EDM servomechanism in between the work piece and the tool. Copper tool electrode is used for the experimentation purpose whose diameter is 20mm and length is 50 mm. The pictorial representation of utilized copper tool electrode is presented in Figure 1.

Figure 1: Copper tool electrode utilized for experimentation

Moreover, initial weight of the copper tool electrode is measured with electric balance (range 0.1-10) mg. Also, the depth of cut is taken a 1 mm for all experiments and kept constant throughout the experimentation. After, each experimentation, the weight of the electrode is measured against the machining time in order to identify the rate of change in the weight of electrode due to erosion of electrode material. The following equations is employed in order to identify the EWR

$$\mathrm{EWR(mg/min)} = \frac{E_i - E_f}{M_t}$$

Where, E_i is the initial weight of copper electrode before each experiment; E_W is the final weight of copper electrode after completion of each experiment; M_t is the machining time of each experiment.

Based on literature survey and the preliminary investigations, four process parameters are scrutinized i.e. pulse ontime, pulse offtime, servo voltage, spark gap as input parameters where EWR is selected as an output response. Taguchi L_9 orthogonal array is utilized for performing experiments and each process variable is varied at three levels. The range of each factor varied at three different levels are shown in table 1.Table 2 represents L_9 Orthogonal Array and collected experimental data against the process parameters.

Table 1: Levels of Input Parameters

Parameters	*Notations*	*Units*	*Level of variations*		
			1	*2*	*3*
Pulse on Time	(Ton)	µs	100	200	300
Pulse Off Time	(Toff)	µs	20	22	24
Gap Voltage	(Vg)	v	50	60	70
Spark Gap	(Sg)	mm	0.05	0.1	0.15

Table 2: Design of experiment (L_9) Orthogonal Array and collected experimental data

Exp No	*Taguchi L_9 Orthogonal Array*				Collected experimental data
	Ton	*Toff*	*Vg*	*Sg*	*EWR (mg/min)*
1	100	20	50	0.05	1.05
2	100	22	60	0.1	1.25
3	100	24	70	0.15	1.50
4	200	20	60	0.15	1.40
5	200	22	70	0.05	1.50

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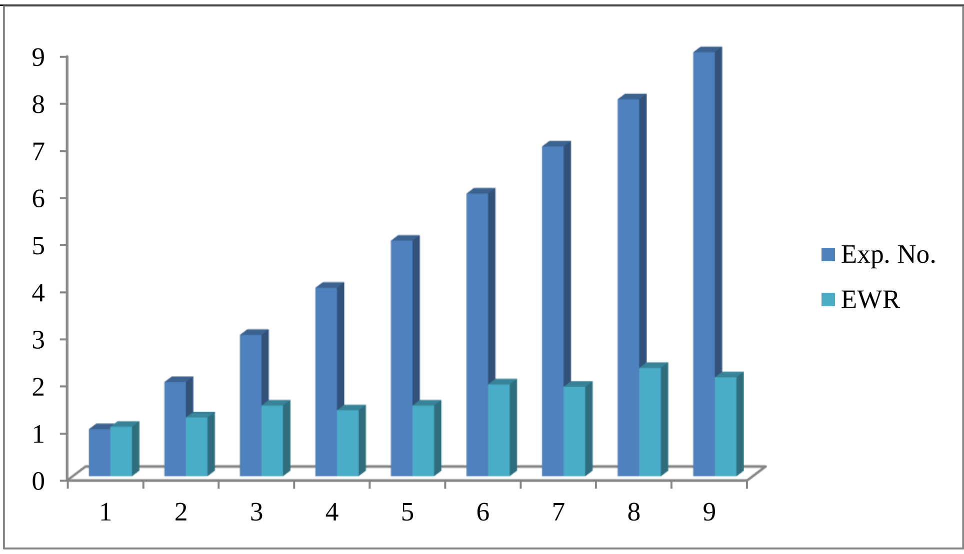
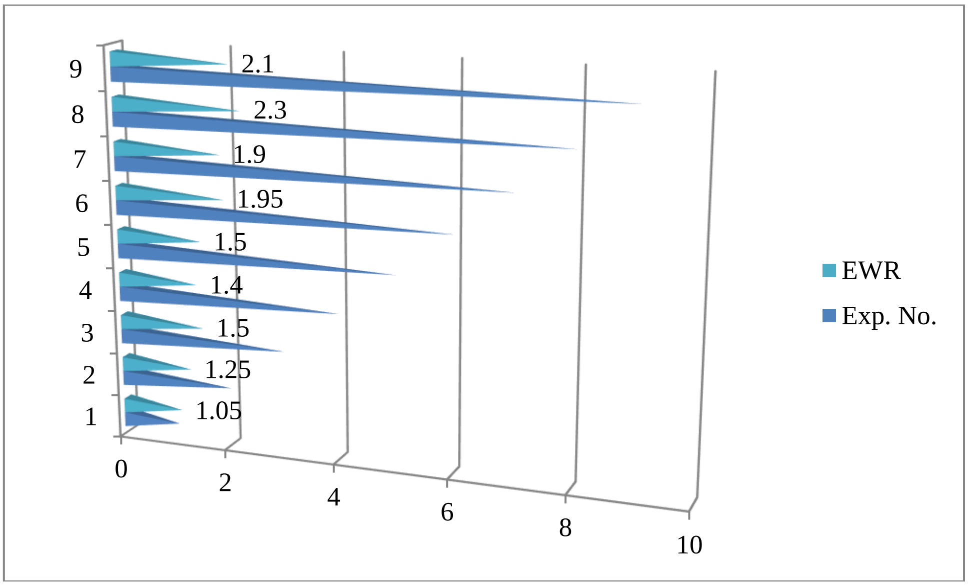
6	200	24	50	0.1	1.95
7	300	20	70	0.1	1.90
8	300	22	50	0.15	2.30
9	300	24	60	0.05	2.10



Figures 2: Variation of EWR

7. Result and Discussion

Based on experimental data study has been carried out to identify the effect of each control process parameters on EWR. Figures 2 represent the variation of EWR for each experiments under combination of different control parameters settings. Moreover, Figures 3 represents show the effect of Ton, Toff, Vg and Sg against each experimentation for EWR during machining over EDM. Moreover, the effect of Vg and Sg over EWR is plotted in Figure 4.



Figures 3: Effect of *Ton*, *Toff*, *Vg*, *Sg* on EWR

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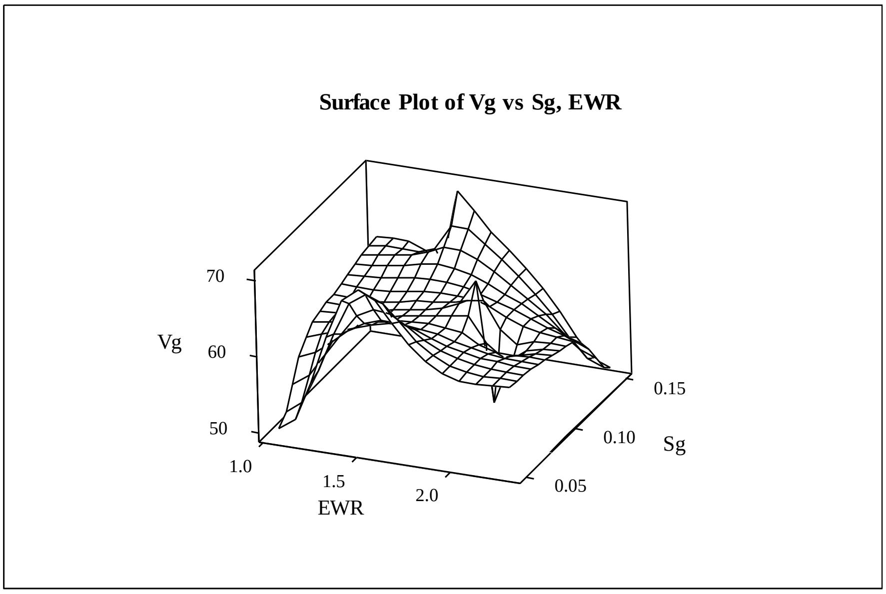

Figure 4: Effect of Vg and Sg over EWR

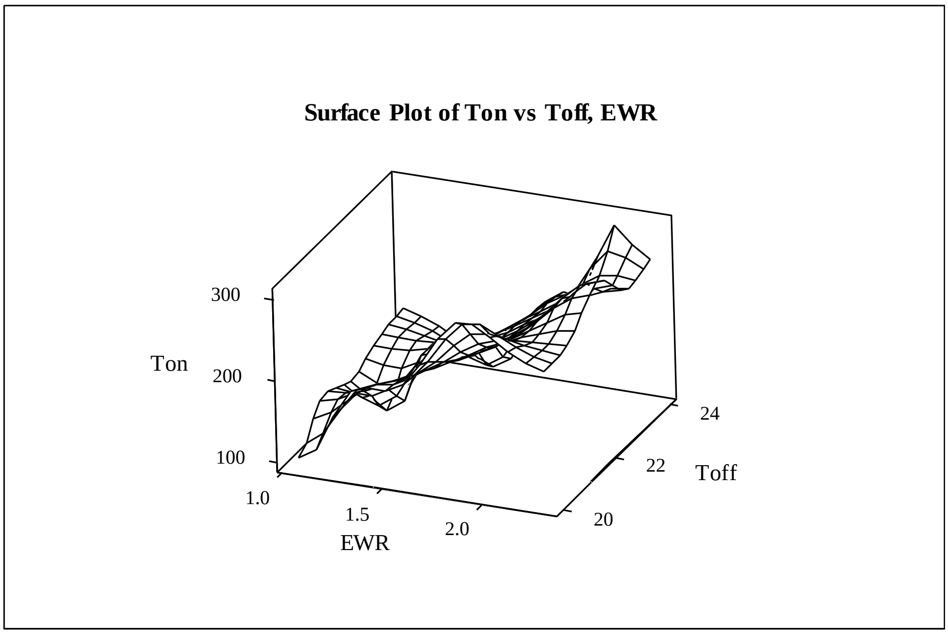

Figure 5: Effect of Ton and Toff over EWR

It is found that the most preferable process condition for optimizing output response is $Ton_1Toff_1Vg_2Sg_1$ as shown in Fig. 6. Moreover, Interaction plot between Ton, Toff, Vg and Sg is also observed in order to identify the effect of individual independent process variable over another as shown in Fig. 7.

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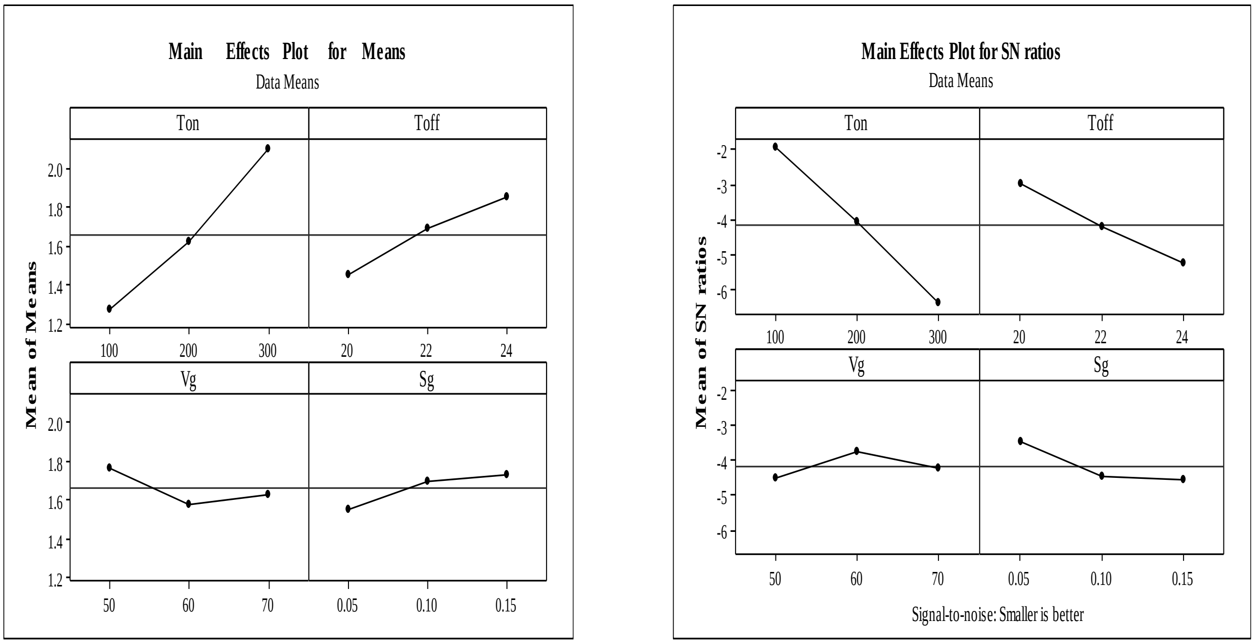

Figure 6: Main effect plot and S/N Ratio Plot for EWR

It is found that increase in discharge energy leads to strong sparks, which heats up the work piece material to a very high temperature and enhances the erosion process, resulting in higher electrode wear. It is also found indeed necessary to identify the impact of Ton and Toff over EWR (Figure 5). It is found as the pulse on time increase, the pulse duration increases, results in more heat transformation to the work piece and increases the EWR.

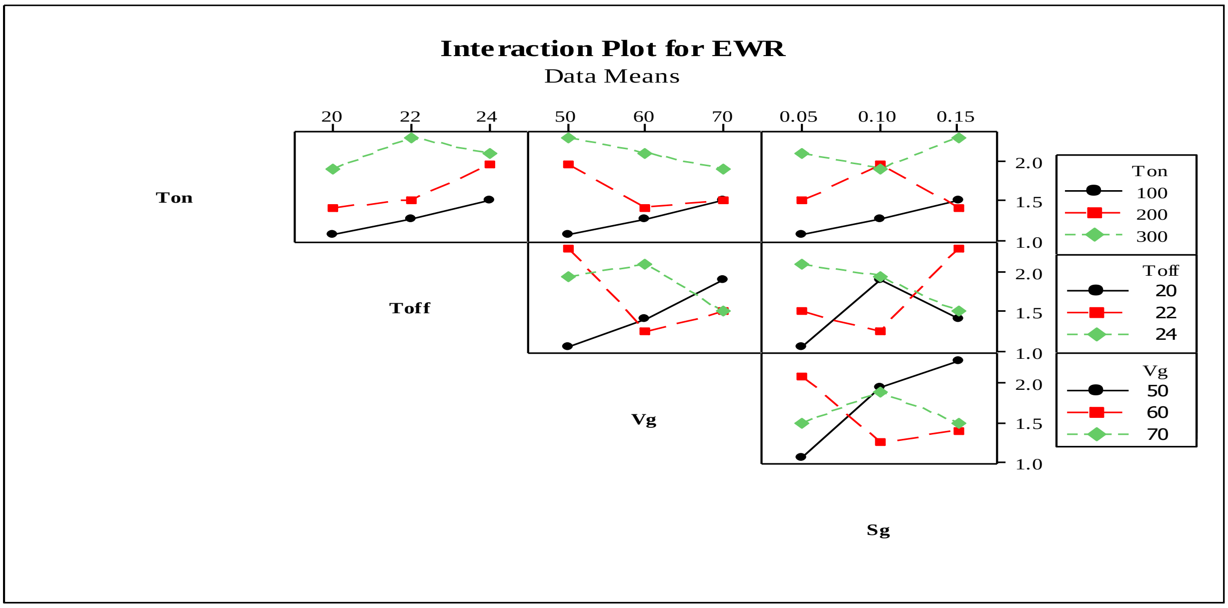

Figure 6: Interaction plot for control process parameters

8. CONCLUSION

In present investigation, Inconel 825 super alloy is employed in EDM to evaluate the optimal setting between considered controllable process parameters i.e. Ton, Toff, Vg and Sg on EWR. For assessing the output responses, Taguchi L_9 orthogonal array design approach is efficiently applied. Furthermore, S/N ratio analysis has been carried out to identify the impact of controllable variables. It is found that optimal process parameters setting is $Ton_1Toff_1Vg_2Sg_1$ for minimizing EWR. The results clearly depict that the combination of independent process parameters i.e. Ton, Toff, Vg and Sg is found as 100, 20, 60 and 005 for optimizing EWR. Moreover, Interaction between Ton, Toff, Vg and Sg is also observed in order to identify the effect of individual controllable variable over another.

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