International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:9, No:6, 2015

Study of the Effect of Inclusion of TiO_2 in Active Flux on Submerged Arc Welding of Low Carbon Mild Steel Plate and Parametric Optimization of the Process by Using DEA Based Bat Algorithm

Sheetal Kumar Parwar, J. Deb Barma, A. Majumder

***Abstract*—**Submerged arc welding is a very complex process. It is a very efficient and high performance welding process. In this present study an attempt have been done to reduce the welding distortion by increased amount of oxide flux through TiO_2 in submerged arc welding process. Care has been taken to avoid the excessiveness of the adding agent for attainment of significant results. Data Envelopment Analysis (DEA) based BAT algorithm is used for the parametric optimization purpose in which DEA is used to convert multi response parameters into a single response parameter. The present study also helps to know the effectiveness of the addition of TiO_2 in active flux during submerged arc welding process.

***Keywords*—**BAT algorithm, design of experiment, optimization, submerged arc welding.

I. Introduction

THE quality of a product is governed by the manufacturing processes involved amongst which welding plays a crucial role. Welding is a very complex manufacturing process as numerous process variables such as current, voltage, carriage speed, wire speed, stick out distance, flux, consumables etc. are involved which finally governs the quality of the final welded products. Post welding effect may account for development of thermal stress and strain termed as residual stress and distortion respectively, due to the non-uniform heating and cooling cycle and also non-uniform expansion and contraction of weld and surrounding base material [1]. The present study is aimed to identify the factors affecting distortion and also to provide some solution for suitable controlling and subsequently minimizing the distortion during submerged arc welding of mild steel plates.

S. W Wen et al. [2] had investigated on heat transfer characteristics in the fusion and heat effected zone during submerged arc welding of thick wall pipe lines. Effects of process parameters and weld bead geometry were evaluated with and without the consideration of residual stress and strain. They concluded that the geometrical distortion as well as residual stress and strain caused by welding can be minimized through process optimization. M. Aghakhani et al. [3] reported the applicability of fuzzy logic to predict the weld bead penetration in SAW process. The input process parameters such as arc voltage, welding current, welding speed, electrode stick out distance and thickness of TiO_2nano particles were considered for developing a fuzzy logic model. The response parameter considered in the model was weld bead penetration. It was investigated that the developed model was accurate and reliable for prediction of the weld bead penetration. The effort of flux on shape variance of TIG weldment was investigated by [4]. The experimental results obtained from active flux TIG welding (A-TIG) showed that the penetration increases initially and decreases steeply with increase of active flux on the weld bead and the penetration was found to be much larger when quantity of flux was low and reduced sharply when the quantity was over a critical value. They concluded that the critical value of the flux quantity should be obtained to control the weld penetration of weld bead in A-TIG welding. The effect of active flux on the marangoni convection in the weld pool during GTA welding was investigated by [5]. The results revealed that depth by width ratio of the weld pool was in close relation to the oxygen content in the pool. It was observed that the oxygen content in the weld metal increased with the quantity of flux used. Further, the investigation revealed that the surface tension gradients on the weld pool surface was altered by the oxygen from the decomposition of the flux in the weld pool thus thereby changing the direction of marangoni convection and the depth of penetration. M. M. Mahapatra et al. [6] had conducted experiments on Submerged arc welding (SAW) of mild steel and it was concluded that fusion and adequate top and bottom reinforcements in 10 and 12 mm thick plates can be obtained in a single-pass submerged arc weld without any edge preparation using a flux-filled reusable backing strip and suitable welding process parameters. They had reported that angular distortion was less when constraints were applied at the two ends of the plates. K. H. Tseng et al. [7] had investigated the effect of nitrogen added in argon shielding gas on the angular distortion of austenitic stainless steels. An auto-genous gas tungsten arc welding had been performed on austenitic stainless steels 304 and 310 to produce a bead-on-

Sheetal Kumar Parwar is an Ex P.G. student of the National Institute of Technology Agartala, India (e-mail: parwarsheetal@gmail.com).
Dr. J. Deb Barma is an Assistant Professor in the Department of Mechanical Engineering, of the National Institute of Technology Agartala, India (phone: +919436120189; fax: +91381-2346-630; e-mail: debbarma_john@rediffmail.com).
A. Majumder is an Assistant Professor in the Department of Mechanical Engineering, of the National Institute of Technology Agartala, India (e-mail: arindam2012@gmail.com).

plate weld with specific process parameter. The mean vertical displacement method (MVDM) had been used to measure the welding distortion and they concluded that Nitrogen addition in argon shielding gas can increase the amount of heat input and welding angular distortion increases with the increase of nitrogen content in weld metal.

The present work deals with the study of the effect of inclusion of TiO_2 in active flux on various response characteristics and further identification of the optimum parametric combination with the help of DEA based Bat Algorithm.

II. Experimental Procedure and Results

The material selected for the present investigation is l200 mm×75 mm×8 mm low carbon mild steel plates. The chemical composition as per the chemical analysis of the material selected has been presented in Table I. The process parameters chosen for the present study are Wire Speed (Ws), Carriage Speed (Cs), Stick Out Distance (SOD) and Weight % of TiO_2 in the flux. The chemical composition of the flux used is presented in Table II. The levels of the process parameters are chosen based on the pilot experiments performed for identifying the range of experiment and is presented in Table III.

TABLE I
Chemical Composition of Low Carbon Mild Steel Plate

C	Si	Mn	S	P	Cr	Cu
0.13	0.2	0.8	0.014	0.02	0.03	0.02

TABLE II
Chemical Composition of the Flux (AutomeltA55 Flux, Make: Ador Welding Limited, INDIA) used

Sio_2+Tio_2 (wt %)	Cao+Mgo (wt %)	Al_2o_3+Mno (wt %)	CaF_2 (wt %)	Grain Size mm	Basicity Index
30	10	45	15	0.25 − 2.00	1.6

TABLE III
Range of the Factors Used in this Work

Cs (m/min)	Ws (m/min)	SOD (mm)	Arc Voltage (V)	TiO_2 (Weight %)
3.7 to 4.5	0.75 to 0.93	27 to 31	31	7.5 to 12.5

In the present study, TiO_2 is homogenously mixed with the conventional flux in proportion of 7.5% to 12.5% in order to study the effect of alternative flux instead of conventional flux during welding.

Table V shows the three – levels, three – factors Taguchi L9 orthogonal array design matrix consisting of 9 (nine) sets of coded conditions. Three levels are chosen for each process variables. Level 1 stands for the lowest chosen value and similarly level 3 stands for the highest chosen value.

Experimentation was carried out to understand the effect of varying weight percentage (wt%) of TiO_2 on HAZ width, Bead width/Penetration (BW/P) ratio on angular distortion (D θ) and Basicity index on depth of penetration. The Submerged Arc Welding unit that has been used in the present investigation is shown in Fig. 1.

TABLE IV
L9 Orthogonal Array for TiO_2 with their responses

Sl. No.	Ws (m/min)	Cs (m/min)	SOD (mm)	wt % TiO_2	P (mm)	D θ (°)	Tensile Strength (KN)
1	1	1	1	1	5.05	1°56'24''	32.5
2	1	2	2	2	4.97	1°50'24''	34
3	1	3	3	3	4.49	1°40'48''	33.7
4	2	1	2	3	5.64	1°54'0''	38.3
5	2	2	3	1	5.24	2°7'48''	32.9
6	2	3	1	2	4.93	2°31'48''	32.8
7	3	1	3	2	5.73	2°13'12''	34.0
8	3	2	1	3	6.02	2°7'12''	35.7
9	3	3	2	1	5.05	1°52'12''	36

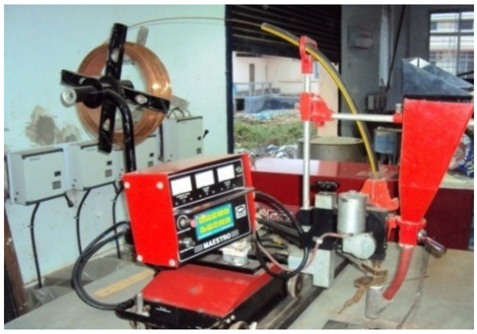
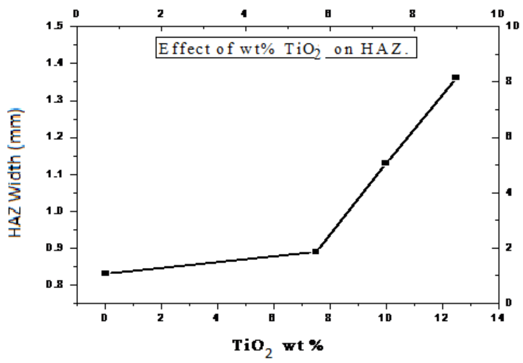


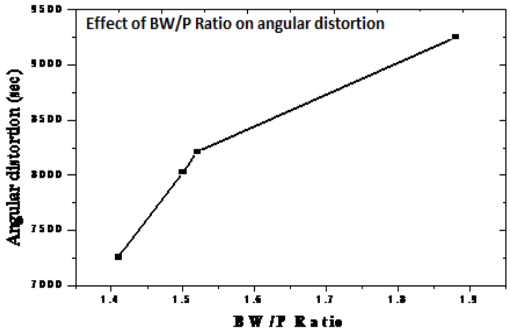
Fig. 1 Photographic view of SAW unit

The results obtained from various experiments conducted at varying weight percentage (wt%) of TiO_2 or Bead width/Penetration (BW/P) ratio or basicity index at a constant wire speed of 4.5 m/min, Carriage speed of 0.84 m/min and stick out distance of 27 mm are plotted in Figs. 2 (a)-(c). Thermal conductivity of TiO_2 is less than that of base metal so it restricts the heat flow within the weld pool. Hence, it increases the width of HAZ as well as depth of penetration and decrease in bead width that have been fairly observed from the experiment. The change in HAZ width with varying weight % of TiO_2 can be seen in Fig. 2 (a). From Fig. 2 (b) it is evident that angular distortion of free weld increases with increase in bead width/ depth of penetration ratio. Basicity index of active flux decreases with increase of wt% of TiO_2. Fig. 2 (c) reveals the fact that depth of penetration increases with decrease in basicity index of the flux.

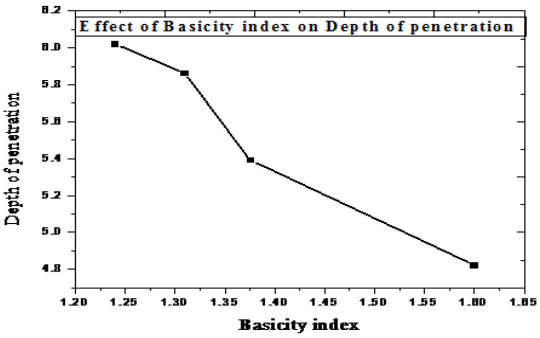


(a)

International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:9, No:6, 2015



(b)



(c)

Fig. 2 Effect of (a) wt% of TiO_2 on HAZ width (b) BW/P ratio on angular distortion and (c) Basicity index on depth of penetration

III. Parametric Optimization

In the present investigation, standard statistical techniques of regression analysis was used to develop mathematical models between the response parameters and the welding process parameters using experimental data listed in Table IV. The final predictive mathematical models thus obtained are shown below:

$$\text{Depth of Penetration} = (2.28+0.047\times Ws-0.11\times Cs-0.010\times(wt\%TiO_2)+0.016\times W_s\times Cs-0.067\times W_s\times SOD-0.047\times Cs\times SOD)^2 \quad (1)$$

$$\text{Tensile strength} = (5.87+0.044\times W_s+0.20\times SOD+0.33\times(wt\%TiO_2)+0.41\times W_s\times Cs+0.063\times Ws\times SOD-0.068\times Cs\times SOD)^2 \quad (2)$$

$$\text{Angular distortion} = (+88.57+2.68\times W_s-6.96\times SOD-5.91\times(wt\%TiO_2)-10.04\times Ws\times Cs-4.98\times Ws^2)^2 \quad (3)$$

While, the accuracy of the developed mathematical models were tested using ANOVA. From ANOVA, it was found that the calculated R^2 and adjusted R^2 values for the developed models are in between99.9% to 99.8% and 99.9% to 99.5% respectively, which indicate that the mathematical models are highly significant.

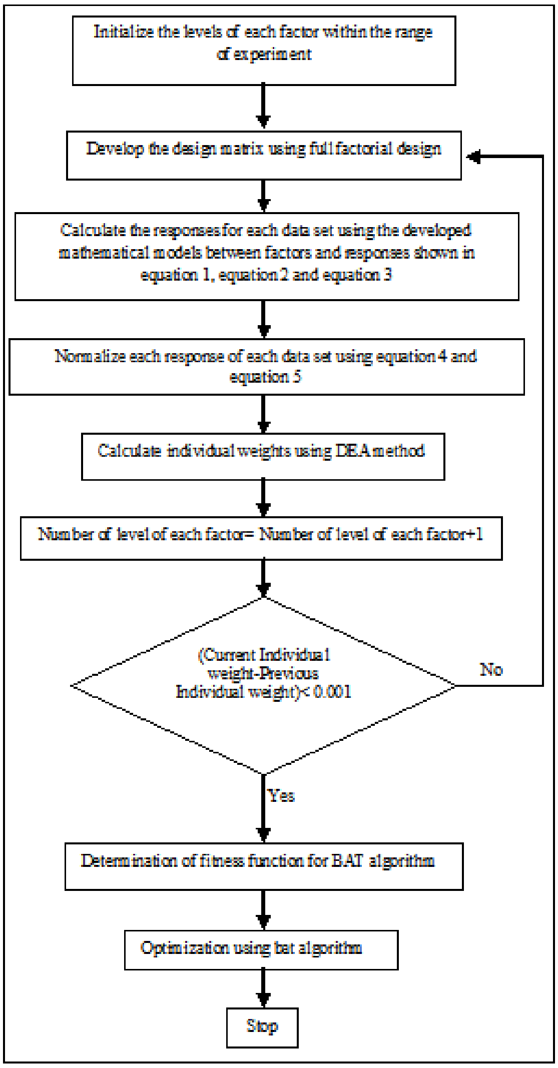


Fig. 3 Flowchart of proposed DEA based BAT algorithm

After determining the mathematical model, DEA based BAT algorithm is used for parametric optimization of angular distortion, tensile strength, and depth of penetration. Fig. 3 presents the block diagram that represents the DEA based BAT algorithm approach.

DEA is used to convert the multi response parameters into single response parameter, calculation of individual weights and for determination of fitness function and then BAT algorithm has been used for optimization purpose. DEA is a linear programming based technique [8] and the steps for this integrated optimization technique can be stated as:

Step1. Selection of the initial levels within the range of experiment.

Step2. Development of the design matrix using full factorial design.

Step3. Calculation of the responses for each data set using the developed mathematical models between factors and responses.

Step4. Calculation of the normalized value of each response in each experimental run.

Equations (4) and (5) show the expressions for calculation of the normalized value of each experimental run.

For Minimization of Any Response

$$F_{ij} = \frac{\min R_{ij}}{R_{ij}} \tag{4}$$

For $i = 1, 2 \ldots.m$ and $j = 1, 2 \ldots.n$

m = no. of response and n = no. of experiments. Here R_{ij} represents the ith response in the jth experiment.

For Maximization of Any Response

$$F_{ij} = \frac{R_{ij}}{\max R_{ij}} \tag{5}$$

For $i = 1, 2 \ldots.m$ and $j = 1, 2 \ldots.n$

Step5. Calculation of individual weights using DEA [8] methodology

If the individual weights are equal to the previous one, then one can move to the next step otherwise the number of levels is increased within the range and then step 2 is followed.

Following equations are used for calculation of individual weights:

$$X_i = \sum_{j=1}^{n} F_{ij} \tag{6}$$

$$IW_i = \frac{X_i}{\sum_{i=1}^{m} X_i} \tag{7}$$

For i = 1, 2 ….m and j = 1, 2 ….n

where i = Response and j = Experiments.

Step6. Determination of fitness function for bat algorithm.

The fitness function can be calculated by using:

$$MRPI = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} IW_i \times F_{ij}}{\sum_{i=1}^{m} IW_i} \tag{8}$$

For $i = 1, 2 \ldots.m$ and $j = 1, 2 \ldots.n$

$$Y(x) = -MRPI \tag{9}$$

where i = Response and j = Experiments, for above all equations and $MRPI$ = Mean response performance index, $Y(x)$ = fitness function.

Step7. Optimization using bat algorithm

BAT algorithm inspired from echo behavior of the micro bats was introduced in 2010 by X.-She Yang [9]. Bats find their food or prey and obstacles in dark by emitting a very loud sound and listens the sound that is rebounded from the surrounding.

For bat algorithm some of the characteristic of bats approximated or idealized are [9]:

1. All bats use echolocation to find the distance from food or prey and obstacles and they can also distinguish them.
2. Bats can fly randomly with velocity V_i at position X_i with fixed frequency f_{min} with variable wave length λ and loudness A_0. They can automatically adjust their wave length and pulse emission rate $r \in [0, 1]$ which depends on the proximity of the target.
3. Loudness varies from maximum positive value A_0 to minimum constant value A_{min}.

A. Movement of Virtual Bats:

Movement of virtual bats to the new position and velocity are given as [9]:

$$f_i = f_{min} + (f_{max} - f_{min}) \times \beta \tag{10}$$

$$V_i^t = V_i^{(t-1)} + (X_i^t - X^*) \times f_i \tag{11}$$

$$X_i^t = X_i^{(t-1)} + V_i^t \tag{12}$$

where $\beta \in [0, 1]$ is random vector and X^* is current global best position.

If solution is selected among best solutions, new solution is produced locally using random walk for each of the bat.

$$X_{new} = X_{old} + \varepsilon \times A_i^t \tag{13}$$

where $\varepsilon \in [-1, 1]$ is a random number.

B. Loudness and Rate of Pulse Emission:

The loudness A_i and rate of pulse emission rate r adjusts its value accordingly as iteration proceeds. Loudness and rate of pulse emission are inversely proportional to each other i.e. loudness decreases with increase in rate of pulse emission and so the bat closes to its prey [8]-[10]. And equations for this are:

$$A_i^{(t+1)} = \alpha \times A_i^t \tag{14}$$

$$r_i^{(t+1)} = r_i^0[1 - \exp(-\gamma t)] \tag{15}$$

where α and γ are constants.

$$0< \alpha<1 \text{ and } \gamma<0$$

By using the Data Envelopment Analysis (DEA), the individual weights calculated for each response parameter are: Penetration = 0.4119, Tensile strength =0.3595and Angular distortion = 0.2287. Then fitness function has been designed using equations given above (4-6 then 9 and 10). Then this fitness function is used in bat algorithm to get the optimized values of input parameter to get the desired value of output one in the SAW process. Fig. 4 shows the relation between fitness value and the number of iteration of TiO_2.

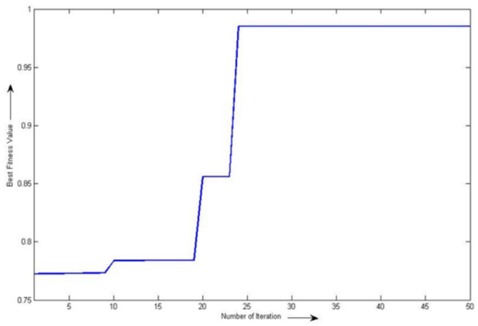


Fig. 4 Relation between best fitness value and number of iteration

C. Prediction Capability of the Developed Model

After predicting the optimal process parameters the performance of the developed model was checked by comparing the optimal condition with the initial condition. The initial experimental and predicted results are shown in Table V.

TABLE V
COMPARISONS OF INITIAL AND OPTIMAL PARAMETRIC CONDITIONS

	Initial Welding Parameters	Predicted Optimal Welding Parameters
Factors	Wire speed (3.7 m/min) Carriage speed (0.75 m/min) Stick Out Distance (27 mm) Wt % of TiO_2 (7.5 %)	Wire speed (3.7 m/min) Carriage speed (0.75 m/min) Stick Out Distance (27 mm) Wt % of TiO_2 (7.5 %)
depth of penetration (mm)	5.05	6.0644
angular distortion (θ°)	1°56'24''	0°56'24''
tensile strength (KN)	32.5	45.84

IV. CONFIRMATIVE TEST

The present investigation consists of a confirmatory test which was done to validate the optimized parametric condition. The results are shown in Table VI.

TABLE VI
RESULTS OF THE CONFIRMATION TEST

	Predicted Optimal Welding Parametric Condition	Observed Optimal Welding Parametric Condition	
Factors	Wire speed (3.7 m/min) Carriage speed (0.75 m/min) Stick Out Distance (27 mm) Wt % of TiO_2 (7.5 %)	Wire speed (3.7 m/min) Carriage speed (0.75 m/min) Stick Out Distance (27 mm) Wt % of TiO_2 (7.5 %)	Percentage Error
depth of penetration (mm)	6.0644	6.125	0.99%
angular distortion (θ°)	0°56'24''	1°28'11''	0.56%
tensile strength (KN)	45.84	44.65	2.60%

From Table VI, the percentage errors are found to be very small. Thus it can be concluded that an excellent reproducibility is confirmed by the confirmation test results.

V. CONCLUSION

The present work concluded the detail experiments to investigate the effect of inclusion of TiO_2 in active flux on to the depth of penetration, angular distortion and its tensile strength of the weld joint. Experiments were done to join the two plates considering the butt joint SAW process of mild steel plates with (200×75×8) mm in dimensions. The primary results are concluded as follows.

- SAW process with addition of TiO_2 in active flux achieves an increase in depth of penetration as well as decrease in bead width.
- Activated SAW process with TiO_2 can increase the joint penetration and weld depth-to-width ratio decreases with increase in wt% of TiO_2, which significantly reduces the angular distortion of the weldment.
- It is obvious by the results that width of HAZ increases with increase amount of oxide contents.
- In the BAT algorithm the weights can be assigned randomly or equally but with the help of DEA weights are assigned logically.
- This technique is very helpful in converting a multi response problem into single response optimization problem.
- This technique is very efficient for solving any type of decision making problems especially in the field of manufacturing where more than one response is needed to be optimized.

REFERENCES

[1] Rajput, R. K., "A Textbook of Manufacturing Technology", 1st ed. Ed. New Delhi: Laxmi Publication, 2007, pp. 292.
[2] Wen, S. W., Hilton, P., & Farrugia, D. C. J. "Finite Element Modelling of a Submerged Arc Welding Process" *Journal of Materials Processing Technology*, 2001, Vol*119*(1),pp. 203-209.
[3] Aghakhani, M., Ghaderi, M. R., Karami, A., &Derakhshan, A. A.. "Combined Effect Of Tio2 Nanoparticles and Input Welding Parameters on the Weld Bead Penetration in Submerged Arc Welding Process using Fuzzy Logic", The International Journal of Advanced Manufacturing Technology, 2014, Vol. 70(1-4),pp 63-72.
[4] Xu, Y. L., Dong, Z. B., Wei, Y. H., & Yang, C. L., "Marangoni Convection and Weld Shape Variation in A-TIG Welding Process", Theoretical and Applied Fracture Mechanics", 2007, Vol. 48(2), pp. 178-186.
[5] Lu, S., Fujii, H., Sugiyama, H., Tanaka, M., & Nogi, K., "Weld Penetration and Marangoni Convection with Oxide Fluxes in GTA Welding", Materials Transactions, 2002, Vol. 43(11), pp. 2926-2931.
[6] Mahapatra, M. M., Datta, G. L., Pradhan, B., & Mandal, N. R. (2006). "Three-Dimensional Finite Element Analysis to Predict the Effects of SAW Process Parameters on Temperature Distribution and Angular Distortions in Single-Pass Butt Joints with Top and Bottom Reinforcements". International Journal of Pressure Vessels and Piping", 2006, Vol. 83(10), pp. 721-729.
[7] Tseng, K. H., & Chou, C. P. (2003),"The Study of Nitrogen in Argon Gas on the Angular Distortion of Austenitic Stainless Steel Weldments". Journal of materials processing technology", 2003, Vol. 142(1), pp. 139-144.
[8] R. Y. M. Nakamura, L. A. M. Pereira, K. A. Costa, D. Rodrigues, J. P. Papa, "BBA: A Binary Bat Algorithm for Feature Selection", Department of Computing S˜ao Paulo State University Bauru, Brazil.

[9] X. S. Yang, "A New Metaheuristic Bat-Inspired Algorithm, in: Nature Inspired Cooperative Strategies for Optimization", (NISCO 2010) (Eds. J. R. Gonzalez et al.), Studies in Computational Intelligence, Springer Berlin, 2010, Vol. 284, Springer, pp. 65-74.
[10] Usha Reddy, V., Manoj, A., "Optimal Capacitor Placement for Loss Reduction in Distribution Systems Using Bat Algorithm", IOSR Journal of Engineering (IOSRJEN), Volume 2, Issue 10 (October 2012), pp 23-27.