

## Table of Contents

<b>Title page</b>	i
<b>Copyright Page</b>	ii
<b>Organizers</b>	iii
<b>Conference Committees</b>	v
<b>Keynote Speakers</b>	xiv
<b>Honoured Guests</b>	xvi
<b>Session Chairs</b>	xvii

## Keynote Addresses

<b>1. From Data Integrity to Inference Integrity</b>	<b>1</b>
<i>Prof. Subhashish Mazumdar, Associate Professor, Department of Computer Science &amp; Engineering New Mexico Tech, New Mexico.</i>	
<b>2. Multi-granular Optical Networks</b>	<b>2</b>
<i>Prof. Suresh Subramaniam, Department Chair and Professor, School of Engineering and Applied Sciences, George Washington University, Washington D.C.</i>	
<b>3. Taming Infinities in the Modeling of Radiofrequency Miniaturized Devices and Designing Physics-inspired Regularization Techniques</b>	<b>3</b>
<i>Prof. Alireza Baghai-WadjiHead, Electronics and Computer Engineering, University of Capetown, Capetown, South Africa.</i>	
<b>4. Connected Vehicles and Internet of Things</b>	<b>5</b>
<i>Prof. Celimuge Wu, Associate Professor, Department of Computer and Network Engineering Graduate School of Informatics and Engineering, The University of Electro-Communications Tokyo, Japan.</i>	
<b>5. Reliability in IoT Era</b>	<b>6</b>
<i>Prof. Tan Cher Ming, Nanoelectronic device and technology (Reliability and failure physics), Department of Electronic Engineering, Chang Gung University, Taiwan</i>	
<b>6. Telecommunication and Network Knowledge Maps</b>	<b>7</b>
<i>Prof. M. E. Fayad, Professor, Computer Engineering Dept., College of Engineering, San José State University, San José, California</i>	

- 7.**
**Paving the Way Towards 5G Wireless Communication Networks**
**8**
- Prof. Mohamed Slim Alouini, Professor, Computer, Electrical and Mathematical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Saudi Arabia*
- 8.**
**From sensors to sensor networks: a journey of innovation**
**9**
- Prof. Alexe Bojovschi, Professor, Communication Technologies Research Center, RMIT University, Melbourne, Australia*
- 9.**
**Evolution of technology and users requirements of factory communication systems from the 3rd to the 4th Industrial Revolution**
**10**
- Prof. Géza Haidegger, Senior Research Engineer, Institute for Computer Science and Control, Hungarian Academy of Sciences, Hungary*
- 10.**
**Design and Development of Nanostrip Patch Antenna for Optical Communication System by Using Artificial Electromagnetic Materials**
**11**
- Dr. N. P. Yadav, Research Scientist, Nanjing University of Science and Technology, Nanjing, China*
- 11.**
**Closed-form Design of Optimal Equiripple FIR filters**
**12**
- Prof. Pavel Zahradnik, Professor, Faculty of Electrical Engineering, Dept. of Telecommunication Engineering, Czech Technical University, Prague, Czech Republic*
- 12.**
**10 years of Radio-Climatological Modelling in Southern Africa**
**13**
- Prof. Thomas Joachim Odhiambo Afullo, Professor, Discipline Academic Leader, University of Kwazulu-Natal, Durban, South Africa*
- 13.**
**Smart Spectrum Awareness in Future Wireless Communications: State-of-the-art, Open Challenges and the Way Forward.**
**14**
- Prof. Miguel Lopez Benitez, Assistant Professor, Dept. Electrical Eng. & Electronics, University of Liverpool, UK*
- 14.**
**Outsourcing Secured Machine Learning (ML)-as-a-Service for Causal Impact Analytics in Multi-Tenant Public Cloud**
**15**
- Prof. Yuh-Jong Hu, Professor, Emerging Network Technologies (ENT) Lab, Department of Computer Science, National Chengchi University, Taipei, Taiwan.*
- 15.**
**Fabrication and Characterization of Colloidal Quantum Dots Based Photodetectors.**
**16**
- Prof. Satyabrata Jit, Department of Electronics Engineering, IIT-BHU, Varanasi, India*
- 16.**
**Extending the Scaling Limits of CMOS by Novel Device Architecture: Nanoscale RingFET.**
**17**

*Prof. Mridula Gupta, Department of Electronic Science, University of Delhi, South Campus, Delhi, India*

17. **Non-invasive RF Sensors: Design and Analysis** 18

*Prof. Nagendra P. Pathak, Department of Electronics and Communication Engineering, IIT Roorkee, Uttarakhand, India*

18. **Telecommunication Revolution changed Life** 19

*Prof. J Ram Kumar, IIT Kanpur*

## **Track 1-Telecom Technologies**

1. **Multi-Standard Radio for 2G to 5G** 20

*PallaviNeog , Rabindranath Bera*

2. **Feature Selection Approach for Reducing The Power Consumption For a Greener Environment** 25

*Deepshika Nagpal, Rashi Srivastava, Deepti Mehrotra, Anuranjana*

3. **Design of Framework and Analysis of Internet of Things at Data Link Layer** 30

*Geetika Sharma, Nitin Pandey, IqraHussain , Sunil Kumar Khatri*

4. **Framework for authentication and access control in IoT** 34

*KossiOwoude Bate, Naresh Kumar, Sunil Kumar Khatri*

5. **Realtime Wireless Data Collection, Analysis and Processing using Xbee Radios and Java** 40

*R.K. Dhammi , K.M. Soni, S. Selvam ,Prabhdoyal Singh*

6. **An Intelligent Spectrum Handover Scheme for Cognitve Radio Ad hoc Networks Using ANFIS With ANN** 46

*Shefali Modi, Mahendra Kumar Murmu*

7. **A Wearable NFC Wristband for Remote Home Automation System** 52

*Osheen Bindroo, Komal Saxena, Sunil Kumar Khatri*

8. **Proposed routing protocols for clouds** 58

*Gaganjot Kaur, SugandhiMidha*

9. **Energy Efficient Routing Algorithm with Multihop Data Aggregation** 63

*Shefali Gautam,Abhishek Kumar, Supreet Kaur*

10. **An Approach to Improve BEST-MAC: Bit map Assisted Efficient Scalable TDMA-Based MAC protocol Using Optimal Cluster Head Selection** 69

*Manju Gangwar, Rakesh Kumar*

## **Track 2-Wired and Wireless Communication**

11. **A Tri-band Circular Patch Microstrip Antenna with Different Shapes in DGS For Ku and K Applications** 74  
*AshnaKakkar, Nirdosh, ShaliniSah*
12. **Bandwidth analysis of Boomerang slot Rectangular Microstrip Patch Antenna** 79  
*Gaurav Prakash Singh, Mukesh Kumar, RohiniSaxena, J. A. Ansari*
13. **Design and Analysis of Different shape Micro-strip Patch** 84  
*Rohit Garg, Rahul Kumar Verma, Lala Bhaskar, Anshu Molly*
14. **An analysis of slots loaded Rectangular stacked Microstrip Antenna for Multiband Operations** 87  
*Saiyed Salim Sayeed, J.A.Ansari, Mukesh kumar, Gulman, Komal*
15. **Performance evaluation of space codes using 16-qam technique** 92  
*Jasvir Kaur, Shakti Raj Chopra*
16. **An Energy Efficient Hybrid Optimized Routing Protocol for WSN** 98  
*Renu kumari, Rakesh Kumar*
17. **Multi-band Slotted Bowtie Antenna for L, S and C band Applications** 104  
*Rajesh Kumar, Sarika, Malay Ranjan Tripathy, Daniel Ronnow*
18. **Wideband Circularly Polarized Patch Antenna Using Meta-material** 108  
*Anamika, Brijesh Kumar Yadav*
19. **Estimation of Aerodynamic Parameter using Cascade Forward Back Propagation** 114  
*Akanksha Talwar, Gaurav Lokhande, Ritesh Jain, S. Singh*
20. **Taming Infinities in the Modelling of Radiofrequency Miniaturized Devices and Designing Physics-inspired Regularization Techniques** 120  
*A. R. Baghai-Wadji*

## **Track 3- Signal Processing**

21. **Music Component Characterization A Case Study: Female Featured Tracks** 126  
*Shivam Sharma, Vinay Kumar Mittal*
22. **Study of Indian Classical Music by singing Voice Analysis and Music Source Separation** 133  
*Seema Ghisingh, Shivam Sharma, Vinay Kumar Mittal*

23.	<b>Separating the Source Information in Repetition-Dependent Music and enhancing by Real-time Digital Audio Processing</b>	139
	<i>Shivam Sharma, Kishan Kumar ,Vinay Kumar Mittal</i>	
24.	<b>The Effect of Music on Human Mind: A study Using Brainwaves and Binaural Beats</b>	145
	<i>Esther Ramdinmawii, Vinay Kumar Mittal</i>	
25.	<b>Emotional Speech Discrimination using Sub-segmental Acoustic Features</b>	152
	<i>Esther Ramdinmawii, Vinay Kumar Mittal</i>	
26.	<b>CT and MRI Image Fusion using Weiner filter in Dual Tree Framework</b>	159
	<i>ShwetaGoel, Sumit Budhiraja, Anaahat Dhindsa, Nancy Mehta</i>	
27.	<b>An Efficient Algorithm for Facial Landmark Detection using Haar-Like Features with Corner Detection following Anthropometric Constraints</b>	166
	<i>Naveen Kumar Gondhi , Navleen Kour, Sidra Effendi, Keshav Kaushik</i>	
28.	<b>Human Emotional States Classification Based upon Changes in Speech Production Features in Vowel Regions</b>	172
	<i>Abhijit Mohanta ,Vinay Kumar Mittal</i>	
29.	<b>Multimodal medical image fusion using modified weight maps and guided filter</b>	178
	<i>Nancy Mehta , Sumit Budhiraja, Shweta Goel</i>	
30.	<b>IIR Based Digital Filter Design and Performance Analysis</b>	184
	<i>Shapna Rani Sutradhar, Nazmus Sayadat, Ashfiqur Rahman, Sirajum Munira, A.K.M. Fazlul Haque ,Syed Nazmus Sakib</i>	
31.	<b>An Innovative approach based on Skull Stripping for MRI images of Human Brain</b>	190
	<i>Anshika Sharma, Shailendra Narayan Singh, Sushil Kumar</i>	
32.	<b>Comparative Analysis of Conventional 2-Level DWT and Color Plane Watermarking for Telemedicine Applications</b>	194
	<i>Priyanka Verma, Ritulika Ghosh Dastidar, Sheetal Jain, Sneha Potghan</i>	
33.	<b>New Embedding Algorithm for Digital Watermarking using 5-DWT and 2-DCT</b>	201
	<i>Khushboo Agrawal, Amit Gupta</i>	
34.	<b>Performance Analysis of Gabor 2D PCA Feature Extraction for Gender Identification using Face</b>	207
	<i>PoojaYadav, Amarjeet Poonia, Sandeep K. Gupta, Shubh Lakshmi Agrwal</i>	

35. **Intermediate Significant Bit-Based Approach to Image Watermarking using Block Entropy** 212  
*Kunal Verma, Ambar Dutta*
36. **Optimized Dynamic Background Subtraction Technique for Moving Object Detection and Tracking** 218  
*Rahul Dutt Sharma, Shubh Lakshmi Agrwal, Sandeep K. Gupta, AniPrajapati*
37. **Robust Design of Optimal Equiripple Cascade Narrow-Band FIR Filters** 221  
*Pavel Zahradnik, Michal Šusta, Boris Šimák, Miroslav Vlček*
38. **Dynamic Traffic Rule Violation Monitoring System Using Automatic Number Plate Recognition with SMS Feedback** 227  
*R Shreyas, Pradeep Kumar B V, Adithya H B, Padmaja B, Sunil M P*

### **Track 4- Microelectronics**

39. **An Architecture for 32-bit Energy-Efficient Wallace Tree Carry Save Adder** 232  
*Madhu, Jai Gopal Pandey, Gaurav Dhiman*
40. **Design of 3-Bit Current Mode Flash ADC Using WTA Based Current Comparator** 236  
*AayushGoel, Ankit Gupta, Maninder Kumar, Neeta Pandey, Veepsa Bhatia*
41. **Low to High Voltage Wide Range Level Shifter for Dual Rail operation comprising modification in Revised Wilson Current Mirror** 242  
*Sumreti Gupta, Jayesh Kumar, Sunil Kumar*
41. **High Gain Bulk-Driven down Conversion Mixer with Improved Noise Figure for UWB System.** 247  
*Gaurav Bansal, Abhay Chaturvedi, Dheeraj Kalra*
43. **eZaar, The Smart Container** 251  
*Rosarium Pila, Saurabh Rawat, IndarPrakash Singhal*
44. **Look Ahead Carry Adder Using Diode Free Adiabatic Logic Family** 256  
*Vishwas Gosain, Vasudev Grover, Neeta Pandey, Kirti Gupta*
45. **New Grounded FDNR Simulation Circuit with Electronic Control** 260  
*Mayank Srivastava, Ajay Roy, Ramendra Singh*
46. **Improved Design of CMOS1-Bit Comparator With Stacking Technique** 265  
*Arvind kumar, Manoj Kumar*

47.	<b>Design and Development of Multifunction Voltage Relay on FPGA</b> <i>Surbhi Varshney, Swati Jain, Sugandha Gupta, Sakshi, Varun Maheshwari</i>	270
48.	<b>Design and Characterization of Bio-MEMS Flow Cell Sensor for Lab-on-chip Mobile Application</b> <i>Nevidita Sharma, Devesh Kumar, Anwar Shahzad Siddiqui</i>	275
49.	<b>Design of QCA circuits using new 1D clocking scheme</b> <i>Suman Rani, Trilokaya Nath Sasamal</i>	280
50.	<b>Power Efficient SAR ADC Designed in 90 nm CMOS Technology</b> <i>Vijay Pratap Singh, Gaurav Kumar Sharma, Aasheesh Shukla</i>	286
51.	<b>Performance analysis of a low power high speed full adder</b> <i>Paro Bajpai, Priyanka Mittal, Amita Rana, Bhupesh Aneja</i>	291
52.	<b>Comparative study and Implementation of BCD Adders for reversible logic based ALU</b> <i>Shaveta Thakral, Dipali Bansal</i>	296

### **Track 5- Network Security**

53.	<b>Visual Cryptography and Image Processing Based Approach for Secure Transactions in Banking Sector</b> <i>Aaditya Jain, Sourabh Soni</i>	301
54.	<b>A Survey on Comparative Analysis of Tools for the detection of ARP Poisoning</b> <i>Sudhakar, R.K. Aggarwal</i>	306
55.	<b>A.J.CIPHER</b> <i>Aakash, Jitendra Kumar Soni, Bharti Sharma</i>	312
56.	<b>A Security Framework for IOT Devices Against Wireless Threats</b> <i>Himanshu Gupta, Garima Varshney</i>	318
57.	<b>Enhancing Password Security Using Cyclic group Matrix</b> <i>Deepanshu, Mayank Sharma, Subhranil Som, Sunil Kumar Khatri</i>	324
58.	<b>Effort and Coverage Dependent Vulnerability Discovery Modeling</b> <i>Yogita Kansal, P K Kapur, Uday Kumar, Deepak Kumar</i>	329
59.	<b>A Naive Bayes Classifier Approach for Detecting Hypervisor Attacks in Virtual Machines</b> <i>Sadia Ansari, Kanchan Hans, Sunil Kumar Khatri</i>	335

60.	<b>Phishing URL Detection by using Artificial Neural Network with PSO</b> <i>Surbhi Gupta, Abhishek Singhal</i>	341
61.	<b>Integrated malware analysis using machine learning</b> <i>Akash Kumar Singh , Aruna Jain</i>	347
62.	<b>Detecting DDoS attacks in cloud computing using ANN and black hole optimization</b> <i>Gopal Singh Kushwah, Syed Taqi Ali</i>	355
63.	<b>FPGA Design &amp; Implementation of optimized RC5 Block Cipher</b> <i>Lomash Chandra Acharya, Surendra Kumar Bairwa, Jyoti Prakash Purohit, Harish Chandra Kumawat</i>	360
64.	<b>Enhanced Data Storage Security in Cloud Environment using Encryption, Compression and Splitting technique</b> <i>Kajal Rani , Raj Kumar Sagar</i>	366
65.	<b>Biometric based authentication and access control techniques to secure Mobile Cloud Computing</b> <i>Sunil Kumar Khatri, Monica, Vikas Rao Vadi</i>	371
66.	<b>Attacks Resistant Trust Mechanisms for WSN: A Comparative Analysis</b> <i>Komal, Priyanka Ahlawat</i>	378

## **Track 6- Computer Science & IT**

67.	<b>Cloud Deep Down - SWOT Analysis</b> <i>Sugandhi Midha, Gaganjot Kaur, Khushboo Tripathi</i>	383
68.	<b>Novel leader election algorithm using buffer</b> <i>Manisha Ranwa , Purushottam Sharma , Gargi Mehrotra</i>	388
69.	<b>Review of Automatic Sarcasm Detection</b> <i>Shalini Raghav, Ela Kumar</i>	392
70.	<b>Smart transport recommender system</b> <i>Kashish Chopra, Pinki Moun, Kapil</i>	398
71.	<b>Prediction of Heart Disease severity with Hybrid Data Mining</b> <i>Meenal Saini, Niyati Baliyan, Vineeta Bassi</i>	403

72.	<b>Fuzzy Appraisal Approach for Maintainability Assessment of Software System</b> <i>Garima Agarwal, Sanjay Kumar Dubey</i>	409
73.	<b>Smart Medicare Record for Classification of ECG for Atrial Fibrillation using NFC card</b> <i>Yashanjali Sisodia, Kishor Wagh</i>	414
74.	<b>Clustering and Sentiment Analysis on Twitter data</b> <i>Shreya Ahuja, Gaurav Dubey</i>	420
75.	<b>Human Activity recognition in Real world</b> <i>Rashim Bhardwaj, Sushil Kumar, Subhash Chand Gupta</i>	425
76.	<b>Hypervisor based performance characterization: XEN/KVM</b> <i>Deepak Kumar, Amaizo Folly Felix Magloire</i>	431
77.	<b>Challenges of Automated Machine Learning on Causal Impact Analytics for Policy Evaluation</b> <i>Yuh-Jong Hu, Shu-Wei Huang</i>	435
78.	<b>Sentiment Analysis Of Tweets To Identify The Correlated Factors That Influence An Issue Of Interest</b> <i>Jainee Vora, Anu Mary Chacko</i>	441
79.	<b>Big Data as a Challenge and Opportunity in Digital Forensic Investigation</b> <i>Neha Kishore, Sapna Saxena, Priya Raina</i>	447
80.	<b>A novel block matching algorithm based on cuckoo search</b> <i>Kamanasish Bhattacharjee, Sushil Kumar</i>	452
81.	<b>Optimal Election Winning Search Algorithm for Distributed Systems</b> <i>Apurvanand Sahay, Tripty Singh, G. Karthik, Sunil Angadi</i>	457
82.	<b>NLCS Based String Approximation For Searching Indexing Keywords in B-tree</b> <i>Sahil Sharma, Mayank Sharma, Rachna Jain, Sunil Kumar Khatri</i>	461
83.	<b>Fault Toleranace Techniques For Scientific Applications in Cloud</b> <i>Suruchi Talwani, Inderveer Chana</i>	465
84.	<b>An Improved Method for DNA Sequence Compression</b> <i>Govind Prasad Arya, R.K. Bharti, Vishal Garg</i>	470
85.	<b>Optimal generation scheduling of thermal System using biologically inspired Grasshopper Algorithm</b>	474

86. **An Introduction to Few Soft Computing Techniques to Predict Software Quality** 480  
*Neeraj Juneja, Kamal Upreti*
87. **Bank Loan Analysis using Customer Usage Data:A Big Data Approach Using Hadoop** 486  
*Shweta Yadav, Sanjeev Thakur*
88. **Factors affecting Psychological State of Youth in India** 494  
*Ahmad Khalid Nazari, Archana Singh,Suvansh Vaid*
89. **Significant Factors for Detecting Malicious Redirections** 499  
*Kanchan Hans, LaxmiAhuja, S. K. Muttoo*
90. **Analysis of Sentiments & Polarity Computation of Opinions** 503  
*Devendra K Tayal, Sumit K Yadav*

### **Track 7- Telecom Management**

91. **Identifying Factors Influencing Brand-Switching in Telecom Industry** 509  
*Nikhil Vazirani, A. SaiSabitha, AbhayBansal*
92. **Impact of Reliance Jio and the Measures Taken by the Various Service Providers to Counter the Schemes Offered by Reliance Jio** 515  
*Bhanu Prakash Kandpal, PriyankaAgarwal*
93. **Time Complexity of Green Financial Database Algorithms and its Impact on Green Financial Computing** 521  
*Krishna Kumar Singh, SachinRohatgi, Manisha Uprety*
94. **Role of Social Support and Social Network in Employee Intention to Stay: A Study in Selected Telecommunication Organizations in the NCR of Delhi** 526  
*Indranil Mutsuddi, Taranjeet Duggal, Chandranshu Sinha, Ruchi Sinha*
95. **The Role and Impact of Accreditation: Enhancing Quality of Engineering Education** 532  
*Pradeep Kumar, Balvinder Shukla, R. S. Rai*
96. **Evolution of technology and users' requirements of factory communication systems from the 3rd to the 4<sup>th</sup> Industrial Revolution** 536  
*Geza Haidegger*

### **Special Technical Session**

97. **KAFKA: The Modern Platform for Data Management and Analysis in Big Data Domain** 542  
*Rishika Shree, Tanupriya Choudhury, Subhash Chand Gupta, Praveen Kumar*

98. **Detect and Investigation of Upper Airways by using Region on Growing Segmentation during Sleep** 547  
*Venkat Ghodke, PratimaGosavi*
99. **Wi-Gig (IEEE 802.11ad): Future, Trends and Era** 551  
*K. K. Arora, PiyushVyas, Ajay Rupani, Manish Purohit*
100. **A Multiple Bits Simulation obtained by Space Time and Frequency Coding Techniques for Any Complex Rayleigh Channel MIMO-OFDM Communications** 555  
*O. P. Vyas, Piyush Vyas, Ajay Rupani, Manish Purohit*
101. **Web-Based Network Management System implemented using Hibernate, JBoss and Spring Framework** 561  
*Himani Pandey, Himani Rastogi, Charu Gupta, Anuja*

# Optimal generation scheduling of thermal System using biologically inspired Grasshopper Algorithm

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**Abstract**— This paper presents Grasshopper Optimization Algorithm (GOA) for solution of economic dispatch (ED) problem related to electrical power systems. GOA is a novel bio inspired optimization approach that mimics the behavior of grasshopper insect during optimization. To check the feasibility and validity of GOA it is employed to solve three different types of ED problems comprising of small, medium and large scale power systems having different complexity levels. The experimental results show that the GOA method is quite promising for solving a wide range of ED problems very efficiently. The performance of the GOA is found to be superior to other recently reported methods available in literature.

**Keywords**—economic dispatch, valve point loading effect, transmission loss, Grasshopper Optimization

## I. INTRODUCTION

The economic dispatch (ED) is one of the main optimization issues related to modern power system. The goal of ED is to find out the optimal output from a number of committed power generating units, to meet the system load demand, at the lowest possible cost, subjected to practical operational constraints [1]. Modern ED problems are difficult to solve by traditional methods due to practical operational constraints which makes the objective function highly nonlinear as well as discontinuous. Over the last two decades researcher have paid massive attention in solving complex ED problem using bio-inspired(BI) methods due to the facts that BI methods are efficient in finding optimum solution by exploring the search space in effective manner and also it can able to handle complex operational constraints in effective manner.

Among BI methods, population based approach are more common [2,3], which mimics the natural phenomenon during the optimization process. They mainly work on the principal of survival of the fittest and broadly classified in three group, they are evolution based, swarm intelligence based and ecological based algorithm [4]. Among evolution based approach evolutionary programming (EP) [5], genetic algorithm (GA) [6], differential evolution (DE) [7]; Among swarm intelligence based approach partial swarm optimization (PSO) [8], ant colony optimization (ACO) [9], artificial bee colony(ABC)[10], firefly algorithm(FFA)[11], Social spider algorithm(SSA)[12], and most recently bird swarm

algorithm(BSA)[13];the third group having biogeography based optimization (BBO)[14], Invasive weed optimization(IWO)[15], stochastic fractal search(SFA)[16] and root tree optimization (RTO)[17] are applied to solve ED problem with different dimension and complexity level.

As per No-free lunch (NFL)[18] theorem there is no optimization approach available that can solve all types of optimization problem; there is always a chance of improvement. In this point of view here a novel optimization approach GOA (S. Mirjalili 2017) inspired by the behavior of grasshoppers during optimization is applied to solve ED problem with different dimension and complexity level.

This paper is organised as follows: problem formulation is presented in section II, concept behind grasshopper optimization approach is presented in section III. Simulation analysis of ED problem using GSO is presented in section IV, finally conclusion is presented in section V.

## II. PROBLEM FORMULATION

The ED is an important optimization problem related to power system. The objective of ED problem is to minimization of the fuel costs while satisfying associated inequality and equality constraints.

The objective function corresponding to power generation cost can be symbolically represented as:

$$\text{Minimize } F_t^{\text{cost}} = \sum_{i=1}^N f_i(P_i) \quad (1)$$

Where the fuel cost function of the generating units is given by

$$f_i(P_i) = a_i P_i^2 + b_i P_i + c_i \quad (2)$$

Considering VPL effect the cost function is written as:

$$f_i(P_i) = a_i P_i^2 + b_i P_i + c_i + |d_i \sin(e_i (P_i^{\min} - P_i))| \quad (3)$$

Where  $a_i$ ,  $b_i$ ,  $c_i$  are the fuel cost coefficients,  $d_i$  and  $e_i$  represents the coefficients due to valve point loading effect(VPL) of  $i^{\text{th}}$  unit.  $P_i$  is the real power output (MW) of  $i^{\text{th}}$  generator. N is the number of online power generating units used for power dispatch.

The total generation cost is minimized subjected to following operational constrains:

*A) Power Balance Constraints:*

Total power generated by thermal unit must be equal to power demand and transmission losses, and it can be expressed as below:

$$\sum_{i=1}^N P_i = PD + P_L \quad (4)$$

*B) Power generator capacity Constraints:*

The power output of each generating unit must be lie within its maximum and minimum operating limit, which is expressed as:

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad \text{Where } i=1, 2, 3, \dots, N \quad (5)$$

The transmission losses occurring in the system can be expressed using B-loss coefficients as:

$$P_L = \sum_{i=1}^N \sum_{j=1}^N P_i B_{ij} P_j + \sum_{i=1}^N P_i B_{i0} + B_{00} \quad (6)$$

### III. GRASSHOPPER OPTIMIZATION ALGORITHM

The grasshoppers are insects found in nature. They basically are pests that damage the crops. There are two types of swarming behaviour found in grasshoppers during their nymph and adulthood phases. Millions of nymph jumps and moves like polling cylinder and eat all types of vegetables which are present in their path. Whenever they become adult, they form a swarm and migrate over long distance [19]. The lifecycle of grasshopper is shown in Fig. 1(a).

The main characteristics of grasshopper which is implemented during optimization is the slow movement and sudden long distance movement that employees the exploitation and exploration phase of bio inspired algorithm. Food sinking is another important swarming behaviour.

The swarming behaviour of grasshoppers can be written as [19]:

$$\chi_k = r_1 S_k + r_2 G_k + r_3 A_k \quad (7)$$

Where  $\chi_k$ ,  $S_k$  and  $G_k$  represents the position, social interaction, gravity force of  $k^{th}$  grasshopper;  $A_k$  represents the wind propagation and  $r_1, r_2, r_3$  are the random number between [0,1].

$$S_k = \sum_{l=1}^{N_{gs}} S_f(d_{kl})(\overline{d_{kl}}) \quad (8)$$

$$d_{kl} = |x_l - x_k| \quad (9)$$

Here  $d_{kl}$  represents the distance between  $k^{th}$  and  $l^{th}$  grasshopper,  $N_{gs}$  is the number of grasshopper.

The unit vector between  $k^{th}$  and  $l^{th}$  grasshopper represented as:

$$\overline{d_{kl}} = \frac{x_l - x_k}{d_{kl}} \quad (10)$$

The social force between two grasshoppers presented as:

$$S_f = \delta e^{r/t} - e^{-r} \quad (11)$$

Where  $\delta$  is the intensity of attraction and  $t$  is the attractive length scale.

The element  $G_k$  can be calculated as:

$$G_k = g \overline{e_g} \quad (12)$$

Where  $g$  is the gravitational constant and  $\overline{e_g}$  is the unity vector towards centre of earth.

The part  $A_k$  can be computed as:

$$A_k = u \overline{e_k} \quad (13)$$

Where  $u$  is the constant flow and  $\overline{e_k}$  is the unity vector in the direction of wind flow.

As there is no wing during the nymph phase of grasshopper, and hence their movement are highly correlated with wind direction.

Substituting the value of  $S_k$ ,  $G_k$  and  $A_k$  in (7)

$$\chi_k = \sum_{l=1}^{N_{gs}} S_f(|x_l - x_k|) \times \frac{x_l - x_k}{d_{kl}} - g \overline{e_g} + u \overline{e_k} \quad (14)$$

Above equation (14) is used to simulate the interaction between grasshoppers in the swarm. However the above model cannot be used directly to simulation purpose due to improper convergence. The modified equation used for optimization is depicted in (15) as below [19].

$$\chi_k^d = \alpha \left( \sum_{j=1}^{N_{gs}} \alpha \frac{ub - lb}{2} \times S_f(|x_l^d - x_k^d|) \times \frac{x_l - x_k}{d_{kl}} \right) \times \overline{T_d} \quad (15)$$

Where  $\alpha$  reduction coefficient used for reduction for size of comfort zone, repulsion zone and attraction zone,  $ub$  and  $lb$  are the upper and lower limits,  $\overline{T_d}$  is the main goal (best solution).

In above equation the submission term represents the position of grasshopper and it apply interaction phenomenon of grasshopper in nature. The term  $\overline{T_d}$  imitates the tendency to move toward food source. This phenomenon is presented in Fig 1(b).

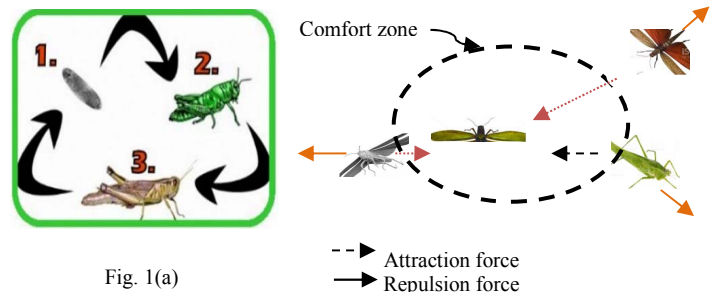


Fig. 1(a)

Fig 1(b)

Fig.1: (a) life cycle of Grasshopper (b) corrective pater of individual Grasshopper in swarm

To balance between exploration and exploitation, parameter  $\alpha$  required to be decreased as iteration progress. This indicates reduction in comfort zone of grasshoppers and it can be represented as:

$$\alpha = \alpha_{\max} - \text{iter} \times \frac{(\alpha_{\max} - \alpha_{\min})}{\text{iter\_max}} \quad (16)$$

Here  $\alpha_{\max}$ ,  $\alpha_{\min}$  can be considered as 1 and 0.0001 respectively,  $\text{iter}$  is the current iteration and  $\text{iter\_max}$  is the maximum number of iteration.

The pseudo code for GSO as per [19] is given below in Fig 2 and the whole implementation procedure of GSO for solution of ED problem is presented using flowchart in Fig.3 below.

```

Initialize the swarm of grasshopper  $X_i (i=1, 2, \dots, N_{gs})$ 
Define  $\alpha_{\max}$ ,  $\alpha_{\min}$  and maximum iteration
Calculate fitness of each search agent
Select T=best search agent
While (iter < max iter)
    Update  $\alpha$  using (16)
    For each searchagent
        Normalise the distance between them
        Update the current best searchagent
        by (15) and
        Check for constraint violation
    end
    update T for better solution
    iter=iter+1
end
Return Best T
    
```

Fig 2: pseudo code for GSO

#### IV. SIMULATION RESULTS AND DISCUSSION

To examine the applicability and effectiveness of the GSO method, three different test cases of ED problems with different dimension and complexity level related to power system is considered here. The code used for study has been developed and implemented in MATLAB 7 and executed on 2.80GHz dual core processor with 2GB RAM. Main control parameters used for GSO are search agent size as 40, maximum and minimum reduction coefficient  $\alpha_{\max}$ ,  $\alpha_{\min}$  can be considered as 1 and 0.0001 respectively. To examine the stability of proposed algorithm 25 independent runs are made for each case study.

##### A) Case 1: 6unit problem with loss

The system has six thermal generation units with convex fuel cost characteristics with transmission loss [20]. The load demand for analysis considered as 1000MW. The optimum solution obtained by GSO is depicted in Table I and statistical comparison of results with recent reported methods are presented in Table II.

The optimum cost obtained by GSO is 52361.2659 \$/hr which is found to be comparable with  $\lambda$ -iteration [20], Particle swarm optimization (PSO) [20] and most recently reported gray wolf optimizer (GWO)[20]. The convergence

characteristic obtained by GSO for this test case is presented in Fig 4.

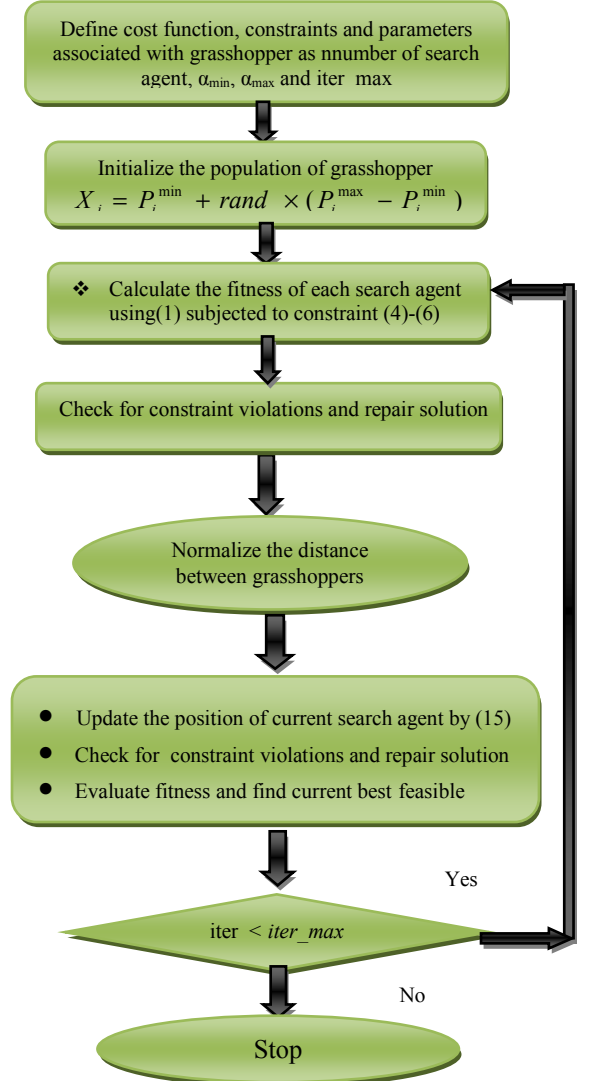


Fig 3: Flowchart for GSO method for solution of ED problem

TABLE I. BEST OUTPUT FOR TEST CASE I

O/P(MW)	$\lambda$ -iter[20]	PSO[20]	**GWO[20]	GSO
$P_{G1}$	40.3969	41.1657	41.1915	41.1640
$P_{G2}$	28.1002	27.7786	27.88	27.7975
$P_{G3}$	187	186.5604	186.4387	186.4601
$P_{G4}$	171.2136	170.5795	170.5973	170.5517
$P_{G5}$	310.721	310.8297	310.6946	310.8914
$P_{G6}$	303.1006	302.568	302.6778	302.6202
Cost(\$/hr)	52362.07	52361.65	52355.7728	52361.2659
$\sum P_G$	1040.5323	1039.4819	1039.4799	1039.4849
$P_{\text{loss}}$	40.5323	39.4821	39.4798	39.4850
PD	1000	1000	1000	1000
CPU time(sec)	NA	NA	6.960886	5.2928

\*\* Actual cost : 52361.27268

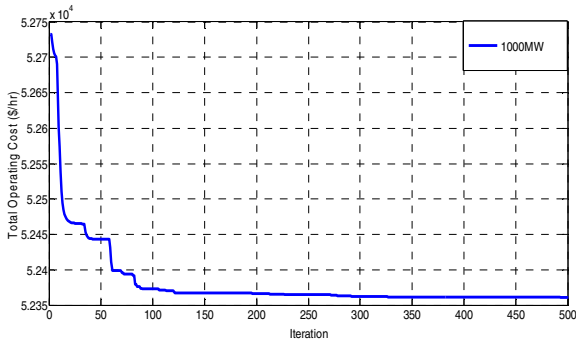


Fig: 3 Convergence Characteristics of Test Case 1 (6 unit problem with loss)

*B)Case 2:13unit problem with valve point loading*

This test system consists of 13 generating units with valve point loading as mentioned in [5]. For analysis purpose load demands for this system are considered as 1800 MW. Transmission loss is not considered here. This test case is complex non convex system and has various local minima. For this complex test case global optima is not reported so far. The simulation results in terms of optimum dispatch obtained by GSO depicted in Table II and statistical comparison of results with other reported methods are presented in Table III.

The comparison of results are made with PSO with time varying acceleration coefficients (PSO-TVAC)[21],social spider optimization(SSO)[12] and most recently reported method root tree optimization(RTO)[17]. Here it is seen that the result obtained by GSO as \$/hr 17963.8292, is found to be better than recent reported RTO (\$/hr 17969.8024) and almost comparable to SSA (\$/hr 17,963.766) in terms of optimum generation cost.

For a complex test case stable convergence obtained by GSO is presented in Fig.4.

TABLE II. BEST OUTPUT FOR TEST CASE II

O/P(MW)	GSO	RTO[17]	SSA[12]	PSO_TVAC [21]
P <sub>G1</sub>	628.3185	628.3072	628.3178	628.319
P <sub>G2</sub>	222.7492	224.3420	149.5731	149.597
P <sub>G3</sub>	149.5996	297.7060	224.3883	222.749
P <sub>G4</sub>	109.8665	60	109.8665	109.867
P <sub>G5</sub>	109.8665	109.8529	109.8665	109.867
P <sub>G6</sub>	109.8665	60	109.8659	109.867
P <sub>G7</sub>	109.8665	60	109.8643	109.867
P <sub>G8</sub>	109.8665	109.7956	109.8664	109.867
P <sub>G9</sub>	60	60.000	60.000	60.000
P <sub>G10</sub>	40	40.000	40.000	40.000
P <sub>G11</sub>	40	40.000	40.000	40.000
P <sub>G12</sub>	55	55.000	55.000	55.000
P <sub>G13</sub>	55	55.000	55.000	55.000
Min cost (\$/hr)	17963.8292	17969.8024	17,963.766	17963.879

TABLE III. COMPARISON OF SIMULATION RESULTS FOR TEST CASE II

Methods	Generation Cost(\$/hr)			S.D
	Min.	Ave.	Max.	
IFEP[5]	17,994.07	18,127.06	-----	-----
PSO_TVAC[21]	17963.879	18154.562	18358.310	-----
GWO[20]	18051.11	NA	NA	NA
C-GRASP-DE[22]	17963.829	17973.636	17978.137	2.962
RTO[17]	17969.8024	18056.9358	18204.6303	NA
GSO	17963.8292	17968.4584	17982.4093	3.6257

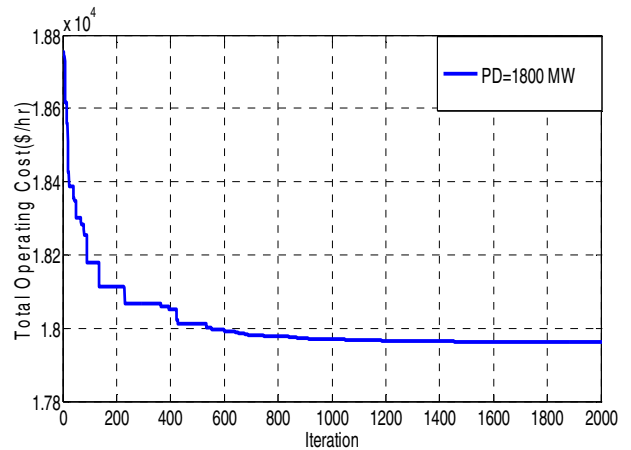


Fig: 4 Convergence Characteristics of Test Case 2 (13unit problem with valve point loading)

*C)Case 3: 38 unit problem*

It is a comparatively larger test case with 38 power generating units. The fuel cost characteristics for this test case is quadratic in nature and transmission loss is not considered here. The input data is adopted from [23]. The power demand for this test case is set at 6000MW. The outcomes in terms of optimum generator scheduling obtained by GSO approach are presented in Table IV. Comparison of results in terms of optimum generation cost are made with is made with hybrid differential evolution with biogeography based optimization (DE/BBO)[24] PSO\_TVAC [21] and moth flame optimization (MFO)[20]. The result obtained by GSO \$/hr 9417235.78617885 in terms of optimum generation cost is found to be significantly better than MFO [20] \$/hr 9419270.188, PSO\_TVAC [21]\$/hr 9,500,448.307 and almost comparable to DE/BBO [24]\$/hr 9417235.786391673. Its Convergence characteristic obtained by GWO is presented in Fig 5.

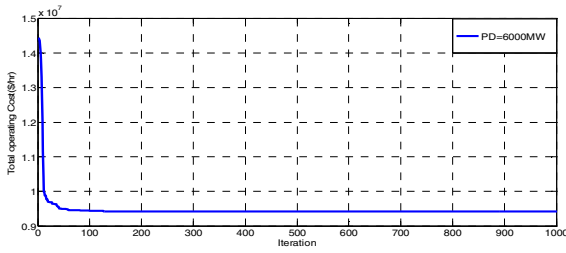


Fig: 5 Convergence Characteristics of Test Case 2(38unit problem)

TABLE IV. BEST OUTPUT FOR TEST CASE III

O/P(MW)	GSO	DE/BBO[24]	BBO[24]	PSO_TVAC [21]
P <sub>G1</sub>	426.60605	426.606060	422.230586	443.659
P <sub>G2</sub>	426.6060611	426.606054	422.117933	342.956
P <sub>G3</sub>	429.6631713	429.663164	435.779411	433.117
P <sub>G4</sub>	429.6631885	429.663181	445.481950	500.00
P <sub>G5</sub>	429.6631859	429.663193	428.475752	410.539
P <sub>G6</sub>	429.66318	429.663164	428.649254	482.864
P <sub>G7</sub>	429.6631796	429.663185	428.119288	409.483
P <sub>G8</sub>	429.663163	429.663168	429.900663	446.079
P <sub>G9</sub>	114	114.000000	115.904947	119.566
P <sub>G10</sub>	114	114.000000	114.115368	137.274
P <sub>G11</sub>	119.7680343	119.768032	115.418662	138.933
P <sub>G12</sub>	127.0728161	127.072817	127.511404	155.401
P <sub>G13</sub>	110	110.000000	110.000948	121.719
P <sub>G14</sub>	90	90.000000	90.0217671	90.924
P <sub>G15</sub>	82	82.000000	82.0000000	97.941
P <sub>G16</sub>	120	120.000000	120.038496	128.106
P <sub>G17</sub>	159.5980342	159.598036	160.303835	189.108
P <sub>G18</sub>	65	65.000000	65.0001141	65.00
P <sub>G19</sub>	65	65.000000	65.0001370	65.00
P <sub>G20</sub>	272	272.000000	271.999591	267.422
P <sub>G21</sub>	272	272.000000	271.872680	221.383
P <sub>G22</sub>	260	260.000000	259.732054	130.804
P <sub>G23</sub>	130.6486261	130.648618	125.993076	124.269
P <sub>G24</sub>	10	10.000000	10.4134771	11.535
P <sub>G25</sub>	113.3050311	113.305034	109.417723	77.103
P <sub>G26</sub>	88.0669157	88.0669159	89.3772664	55.018
P <sub>G27</sub>	37.5050999	37.5051018	36.4110655	75.000
P <sub>G28</sub>	20	20.000000	20.0098880	21.682
P <sub>G29</sub>	20	20.000000	20.0089554	29.829
P <sub>G30</sub>	20	20.000000	20.0000000	20.326
P <sub>G31</sub>	20	20.000000	20.0000000	20.000
P <sub>G32</sub>	20	20.000000	20.0033959	21.840
P <sub>G33</sub>	25	25.000000	25.0066586	25.620
P <sub>G34</sub>	18	18.000000	18.0222107	24.261
P <sub>G35</sub>	8	8.0000000	8.00004260	9.667
P <sub>G36</sub>	25	25.000000	25.0060660	25.000
P <sub>G37</sub>	21.7820858	21.7820891	22.0005641	31.642
P <sub>G38</sub>	21.0621772	21.0621792	20.6076309	29.935
Min Cost (\$/hr)	<b>9417235.786</b> <b>17885</b>	9417235.786 391673	9417633.637 6443729	9,500,448.307

D) Selection of Control Parameters

GSO belong to the bio inspired approach and it need appropriate selection control parameter to solve constrained optimization as the optimal selection of parameter helps to find better solution in less computational time. Test case1, having 6 generation unit system with transmission line loss is used here to analyze to get best tuning parameters of GSO. Total load demand of the system set at 1000MW. As GSO has Three main control parameter as search agent number (NP), maximum reduction coefficient ( $\alpha_{max}$ )and minimum reduction coefficient ( $\alpha_{min}$ ).

The search agent number (NP) is set at 20 and keeping  $\alpha_{max}$  as 1,  $\alpha_{min}$  is varied from 0.00001 to 0.01. Keeping maximum number of iteration 500, simulation analysis has been carried out over 25 number of repeated trail. The statistical performance of GSO with different population size is tabulated in Table V. Here it is observed that with search agent size 40 and  $\alpha_{min}$  as 0.0001, the best results are obtained in terms of minimum cost \$/hr 52361.2716 and average cost \$/hr 52361.3017, and it is considered here for futher simulation analysis.

TABLE V. STATISTICAL PERFORMACE OF GSO WITH DIFFERENT TUNING PARAMETER FOR TEST CASE I

NP	$\alpha_{min}$	Min C	Ave C	Max C	SD
20	0.00001	52361.2799	52361.3461	52361.5123	0.0385
	0.0001	52361.2723	52361.3109	52361.3666	0.0154
	0.001	52361.2763	52361.3054	52361.3468	0.0110
	0.01	52361.2824	52361.3199	52361.3984	0.0184
40	0.00001	52361.2699	52361.3911	52361.5260	0.0393
	<b>0.0001</b>	<b>52361.2716</b>	<b>52361.3017</b>	<b>52361.3580</b>	<b>0.0143</b>
	0.001	52361.2737	52361.3289	52361.3759	0.0146
	0.01	52361.2735	52363.1076	52365.8549	0.99106
60	0.00001	52361.4752	52365.6037	52367.4819	0.9917
	0.0001	52361.2819	52363.2507	52367.4800	1.0155
	0.001	52361.2694	52363.4278	52367.4902	1.1957
	0.01	52361.2765	52362.1902	52365.7885	0.8046

NP: Search agents number, SD: standard deviation

E) Computational efficiency and robustness

For each test case twenty-five independent trails has been carried to authenticate the computational efficiency and robustness of GSO. It is evident from Table I, Table III and Table V that GSO is efficient in terms of obtaining optimum operational cost of thermal generation unit analysed in all

three cases. Statistical result presented in Table III and Table V justifies the robustness of GSO too.

The average CPU taken by GSO is plotted in Fig 6 below, which seems to be obvious considering complexity and dimension of test cases under simulation analysis.

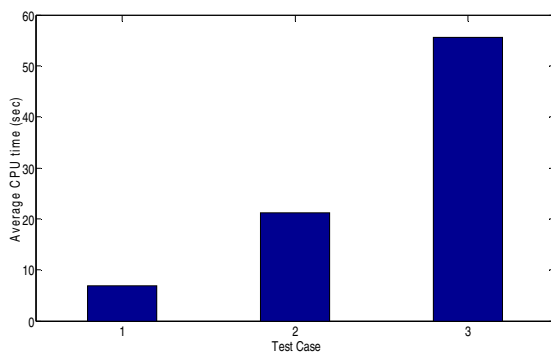


Fig: 6 Average CPU time for different test cases

## V. CONCLUSION

In this paper, grasshopper optimization, a novel bio-inspired optimization approach is implemented to solve ED problems with different dimensions and complexity. To investigate the potential of the algorithm various realistic nonlinear complex constrained problems with and without transmission loss are considered here. The GSO algorithm is comparatively simple, and also easy to implement. The algorithm is tested on three standard test cases and comparison of result is made with other method available in various literatures in terms of optimum operating cost, standard deviation and required simulation time. The solutions obtained by GSO were found to be better for the large dimension test case and almost comparable with other methods for other two small and medium scale test cases with good convergence characteristics. Considering overall simulation analysis and obtained results, we can say that GSO is a robust optimization approach and capable to solve complex constrained real world optimization problems.

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