Fuzzy based Locust Swarm Algorithm for Identification operating state of Electrical Energy System with Multiple units

K. Harinadha Reddy
Electrical and Electronics Engineering, Lakireddy Bali Reddy College of Engineering (A), Mylavaram-521230, NTR district, Andhra Pradesh, India; Jawaharlal Nehru Technological University Kakinada, A.P., India.

***Abstract*—This paper presents, modified locust search algorithm for identification of abnormal operation using a fuzzy control in integrated electrical energy system. Fuzzy membership modifies the locust search and hence proposed fuzzy based locust search algorithm (FB-LOA) is develop for power control in a electrical energy system. Search position of modified locust swarm calculated by the membership for every instant of swarm search control. Control for each locust swarm instant, particle distance d between two adjacent particles is calculated and continuous update the proposed locust search instant. Proposed locust search initiate the conformation of trip signal from distributed generator (DG) circuit trigger pulses under any normal operating event (NOEV) or abnormal operating event (ABEV). Electrical energy system state with two local energy source units is verified with proposed method.**

***Index Terms*—Energy system, operating state, locust swarm optimization, fuzzy control, abnormal operation**

I. Introduction

Electrical energy system with many distribution generator (DG) utilities and they are interconnected to meet load demand of user. Assessing the electrical energy system operation, during a grid [1] control mode when disturbance occurred is also essential requirement. Locust behaviour and its swarm [2], [3] to search for a food and related phenomenon is a famous kind of optimization method. For many energy system units or network operation control will be ensure the optimal assessment of each unit operating state in network. Such locust phenomenon and behaviour is inspired the researchers for using optimal allocation and scheduling problem in energy system along various applications. Inspired from behaviour [4], tunicate swarm algorithm (TSA) is develop by authors and iterative support random optimization is also proffered for various kind of test system and their operating conditions i.e. either normal conditions or abnormal operating conditions. Fuzzy system is one of the control strategy and it can used to develop a optimization model using particle swarm and other bio inspired methods during the operation. To meet the goals of self learning and training, authors develop models by using [5], intelligent self deep learning neuron [6], machine learning based fault detection [7], self learning based classification [8], hybrid system training [9].

Optimization methods used for estimation operating state in integrated power and energy system is also utilised the behaviour of grasshopper [10] and replica of locust procedure implemented in a proposed method. Researchers are concentrate in network operation control and develop predictive structure to stabilize self training particles [11] and used for convolution attention and swarm based genetic control in a application procedure. Optimisation procedure for a control applications, an adaptive theory is implemented for relative movement in particles of grasshopper [12], in various directions and hence optimal solution is defined by authors to achieve the objective of control in application. Authors are represents the motion path for every particle and their optimal location is denoted by the control of structural framework along the adaptive hierarchy procedure used in control, hence the conformation of system operating state. For estimation of maximum required operating state of utility electrical energy system with i) fuzzy control, ii) intelligent control, iii) neural self learning, iii) hybrid methods with optimization and self learning, are preferred by many adaptive strategies in system that consists a multiple units.

Identifying the situations in operation of electrical energy utility system, many disturbances like fault conditions, mismatch conditions and those are recognised by classifiers, resonant neurons, dual stage of power grid connected solar PV control [13], fuzzy system control for operating a voltage source converter of distributed generator [14]. Searching problem with many intelligent techniques became essential task and optimization method are involved to reduce the problem size, likewise locust swarms for multiple optimum dimensionality is given in [15]. Authors are develop a swarm procedure and related algorithm for any kind of parameter identification by framing a number of state estimated rules of distributed generators units like photovoltaic sections of modules

[16]. Hybrid algorithms are designed for known problem and target datasets in an electrical power network and operating state will be estimated either by AI support methods, or decision based support methods. Network control with self designed and deep learning neurons traning using a swarm optimization and they are used to recognize the state of interconnected electrical energy system network during abnormal model [17].

System with multiple power generating units may work at various conditions [18], island schemes [19] and they are required coordination during the individual power control at common point and hence proper energy system operation [20] in an interconnected mode [21], [22] can be assured. Also many situations like disturbance conditions, switching conditions are considered and authors develop a procedure to identify their operating state and hence performance of network. Phenomenon fuzzy set model and related theoretical rules are developed to asses such kind of problems using a proposed modified locust swarm algorithm and also observe the energy system protection during a unnecessary situations are raised in an inter tied electrical energy system.

II. MODIFIED LOCUST SEARCH ALGORITHM WITH TEST SYSTEM

Modified locust search algorithm for an integrated electrical energy system with DG as solar PV system is given in Fig. 1 along locust procedure.

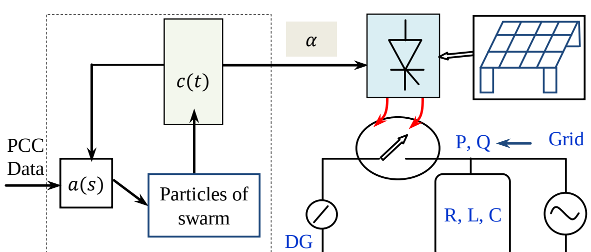

Fig. 1. Structure of modified locust control used in test system

A. Power control in electrical energy system

Power from a main power grid may oscillate due to disturbance at point of common coupling (PCC). Change power, the voltage and frequency variations at PCC of electrical energy system. Power components i.e. active power P and reactive power Q with respect to voltage v and frequency f are main control parameters is electrical energy system. According to load parameters resistance R, inductance L, capacitance C and their variations are given in (1) equation and denoted as ΔR, ΔL and ΔC.

$$R+\Delta R,\ L+\Delta L,\ C+\Delta C \tag{1}$$

Power consumed by the load in a electrical energy system is obtained by (2).

$$P=\frac{V^2}{R+\Delta R} \tag{2}$$

As per voltage variations for a maximum and minimum values i.e. V_{max}, V_{min}, power variations in active power mismatch is obtained by equation (3).

$$\left(\frac{V}{V_{max}}\right)^2-1\leq\frac{\Delta P}{P}\leq\left(\frac{V}{V_{min}}\right)^2-1 \tag{3}$$

As per frequency variations for a maximum and minimum values i.e. f_{max}, f_{min}, power variations in reactive power mismatch is obtained by equation (4).

$$Q_f\left(1-\left(\frac{f}{f_{min}}\right)^2\right)\leq\frac{\Delta Q}{P}\leq Q_f\left(1-\left(\frac{f}{f_{max}}\right)^2\right) \tag{4}$$

Quality factor $Q_f = 1$ in general case and then Q mismatch is calculated by $1-\left(\frac{f}{f_{min}}\right)^2 \leq \frac{\Delta Q}{P} \leq 1-\left(\frac{f}{f_{max}}\right)^2$. Quality factor, Q_f calculated by equation (5).

$$Q_f=R\sqrt{\frac{L}{C}}=\sqrt{\frac{Q_L.Q_C}{Q_L+Q_C}} \tag{5}$$

$Q_L,\ Q_C$ are reactive power consumed by inductive and capacitive loads. Disturbance causes a change V i.e. ΔV, f i.e. Δf and new values of voltage and frequency.

B. Locust search in test model

Search agent $a(s)$ always validated by a particle distance p to take a next agent in swarm search. Outcome of locust, α will be calculated as per search procedure of each particle. Locust swarm control $c(t)$ will decide the search for all instants of particle position. $x_i = r_A a(s) + r_B G_a + r_C A_s$ Term $a(s)$ are the position of social interaction for data x_i. G_i is a gravity force, A_s is a convection of air. Locust random values r_A, r_B and r_C for the scaling. Locust particle control $c(t)$ from a input members x_i, $\dot{x}_i$. Input data x_i is a PCC data V_i or f_i for a i^{th} particle. Variations of V_i, f_i will be a $\dot{V}_i$, $\dot{f}_i$. These data is useful for a locus distance p_i with respect initial particle x_0 as given by (6).

$$p_i=x_0-x_i;\ i=1,\ 2,\ 3,\ ....n \tag{6}$$

Electrical energy system with PCC data variation is depend on the nature of NOEV or nature of ABEV. Locust particles and their behaviour of searching procedure for food and this is important phenomenon which is obtained initial search. Locust behaviour for the i^{th} will be obtained by (7) as its search a(s) all locust.

$$a(s)=x_0+\sum_{\substack{i=1..\\ i\neq 0}}^{...n} p_i\times a_0(s) \tag{7}$$

Distant of i^{th} particle is calculated for observing the force travel in right direction, T_{ar} and left direction T_{al}. In a proposed method only search $a(s)$ along T_{ar}, T_{al} will be taken by locust index w_s. The w_s is determined by T_{ar} by the $a(s)$ elements satisfies the p_i and shown in (8) for the data X elements of T_{ar}.

$$w_s = T_{ar} \cdot (X \overset{f(x)}{\rightarrow} a(s),\ f(x) \subset x_i) \tag{8}$$

During the search w_s is calculated once by assuming the T_{ar} initial direction. Therefore T_{al} is obtained from the opposite locust of maximum position i.e. $1 - w_s$ and given by (9).

$$T_{al} = (1 - w_s)\ \&\ T_{al}^{(max)} = 1 \tag{9}$$

Actual positions is known for index w_s and given by

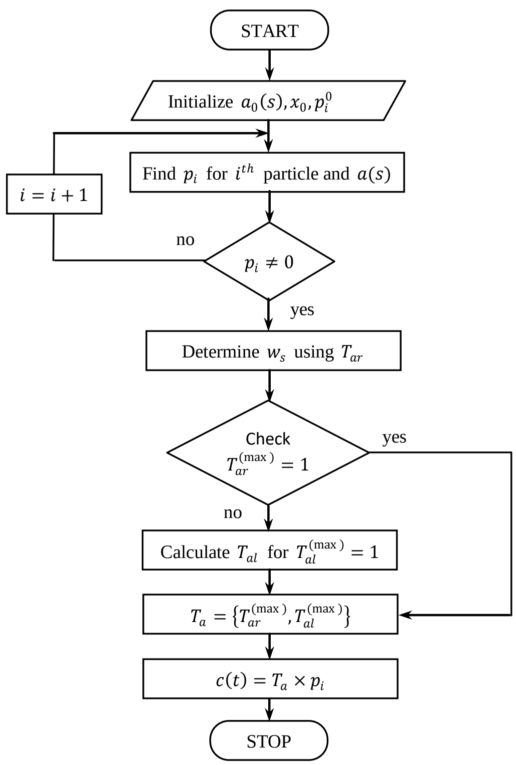

Fig. 2. Flow-chart of modified locust search. (a) R_n. (b) R_a.

expression (10) for a p_i instant.

$$T_a = [T_{al}^{(max)},\ T_{ar}^{(max)}],\ if\ p_i \neq 0 \tag{10}$$

Now the locust index is update by optimal T_{ar}, T_{al} with respect to p_i.

$$c(t) = T_a \times p_i,\ i = 1,\ 2,\ 3,\ ....n \tag{11}$$

Control of modified search in locust particle is given flowchart as illustrated in Fig. 2. Control of locust $c(t)$ and its deviation $\dot{c}(t)$ is input for the fuzzy control to obtain the outcome α as per the data x_i at PCC of energy system. Fuzzy membership of $\mu_c(z)$ will be evaluated by the control $c(t)$ from a operating state of energy system.

III. Proposed Fuzzy Based Search for Control of Electrical Energy System

Electrical energy system operating state is control and identification process is depending on $c(t)$. Fuzzy membership of $\mu_c(z)$ is defined as per input $c(t)$ and $\dot{c}(t)$. Fuzzy rules $r_i = r_1,\ r_2...r_n$ for user defined memberships in a natural language are positive big, positive medium and so on. Interpolation μ_A of $\mu_c(z)$ with each rule r^i with data set A_x is determine by equation (12).

$$\mu_A = \mu_c(z) + \sum A_x \tag{12}$$

Member of μ_A meet the objectives for a both $a(s)$ and w_s and express by equation (13) under constraint c_2 .

$$c_1 = \mu_A^1 \cup \mu_A^2,\quad w_s < 1 \tag{13}$$

Expression (14) gives the objective for constraint c_2, w_s lies above region.

$$c_2 = \mu_A \leftarrow max(\mu_A^1,\ \mu_A^2)\ \ w_s > 1 \tag{14}$$

Constraint c_3, w_s satisfies the locust lies on the region and expression (15) find its value.

$$c_3 = \mu_A \leftarrow min(\mu_A^1,\ \mu_A^2)\ \ w_s = 1 \tag{15}$$

Outcome of locust search is calculated by (16) for a normal c_1, c_2 wit respect to a maximum index w_s operation. Outcome of locust search is calculated by (17) for a normal c_1, c_2 wit respect to a minimum index w_s operation.

$$\alpha^{max} = c_1 \circ w_s\ \vee\ c_2 \circ w_s \tag{16}$$

$$\alpha^{min} = c_1 \circ w_w\ \wedge\ c_2 \circ w_s \tag{17}$$

Goal reached for travelling particle in right and left path i.e. g_r, g_l is calculated by (18) equation. Maximum and minimum values of path are calculated by (19) equation.

$$g_r = \alpha^{max}\ c_3 \geq 0,\ g_l = \alpha^{min}\ c_3 < 0 \tag{18}$$

$$\phi_r = g_r \times \alpha^{max},\ \phi_l = g_l \times \alpha^{max} \tag{19}$$

Entire control of locust search $\alpha(t)$ is obtained finally using (20). Locust search $\alpha(t)$ provides a decision for different ABEV of operating conditions.

$$\alpha(t) = c_1 + c_2 \sum \phi_r + c_3 \sum \phi_l \tag{20}$$

Control output $\alpha(t)$ would be a system control which can be any type multi DG units like solar, wind and other power generating unit.

Algorithm 1 Fuzzy based search algorithm for energy system

Input : Input $c(t), w_s$, A_x, μ_A.
Output: Fuzzy control, $\alpha(t)$
Calculate the w_s for given particle;
Find the μ_A for A_x.
if $w_s < 1$ **then**
  Find $c_1 = \mu_A^1 \cup \mu_A^2)$
  Find $f(x)$
else
  Find $c_2 = \mu_A \leftarrow max(\mu_A^1,\ \mu_A^2)$
end
For w_s=1, $c_3 \leftarrow \mu_A \leftarrow min(\mu_A^1,\ \mu_A^2)$
Obtain g_r, g_l ;
for $\alpha^{max} c_3 \geq 0$ **do**
  Use g_r, α^{max} to find ϕ_r
  `Otherwise`
  Use g_l, α^{min} to find ϕ_l
  Identify the path ϕ_r, ϕ_l;
end
Fuzzy based locust $\alpha(t) \rightarrow$ island control.

IV. Results and Discussions

Two DG units are integrated in a electrical energy system and they operating in different conditions. Data input for a X_i and its elements $i = 1, 2, ...n$, function $f(x)$ is defined for observing the operation of energy system.

A. NOEV, ABEV data

Particles travelling in T_{ar} for NOEV and ABEV shown in Fig. 3. Normal $f(x)$ with $x \subset x_i$ plotted in Fig. 1(a) and T_{ar} variation at $p_i = 0$ is given in Fig. 1(b). Abnormal $f(x)$ with $x \subset x_i$ plotted in Fig. 1(a). T_{ar} variation at $p_i \neq 0$ is given in Fig. 1(b) and also $T_{ar}^{(max)}$ found in a data. Algorithm 1 gives the optimal value

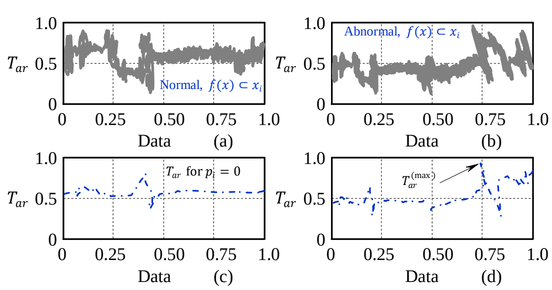

Fig. 3. Particles along T_{ar} for x_i data. (a), (b) NOEV. (c), (d) ABEV.

of $T_{ar}^{(max)}$ as per locust search. Island $\alpha^V(t) \subseteq \alpha(t)$, $\alpha^f(t) \subseteq \alpha(t)$ control is utilized for a identification of $\Delta V,\ \Delta f$.

$$\Delta V = P - P_{ref} + \left(\frac{dP}{dt} + \sum \alpha_i\right) \tag{21}$$

As per Δf or $\Delta\omega$ with $\omega = 2\pi f$ is also control.

$$\Delta\omega = Q - Q_{ref} + \left(\frac{dQ}{dt} + \sum \alpha_i\right) \tag{22}$$

B. Mismatch events

Two DG units are integrated to main power grid and entire control with proposed FB=LOA island method is shown in Fig. 4(a).

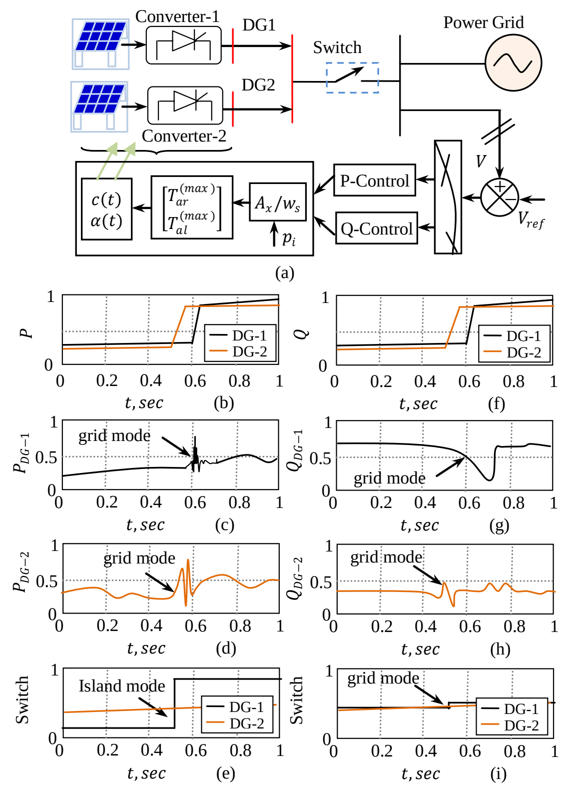

Fig. 4. Mismatch events of P, Q. (a) Electrical energy system with two DG units. (b)-(e) P control. (f)-(i) P control.

Mismatch of P events are given in Fig. 4(b) to Fig. 4(e). Voltage V variation and its P variations are at DG-1 and DG-2 given Fig. 4(b). Individual DG power variations i.e. P_{DG-1}, P_{DG-2} are given in Fig. 4(c), Fig. 4(d). Switching instant of DG-1, DG-2 due to P variations are are given in Fig. 4(e).

Mismatch of Q events are given in Fig. 4(f) to Fig. 4(i). Frequency f variation and its Q variations are at DG-1 and DG-2 given Fig. 4(f). Individual DG power variations i.e. Q_{DG-1}, Q_{DG-2} are given in Fig. 4(g), Fig. 4(h).

Switching instant of DG-1, DG-2 due to Q variations are given in Fig. 4(i). Proposed method is compared with artificial intelligent (AI), artificial neural network (ANN), fuzzy logic control (FLC), machine learning (ML), optimal control methods. Performance of FB-LOA is about 8-10% as compared with adaptive ML, ANN based FLC and mongoose optimization algorithm. Algorithm 2 will

Algorithm 2 Proposed FB-LOA algorithm to generate switching instants.

Input: Power P_{DG-1}, P_{DG-2}
Initialize thresholds X_1, X_2, X_3 and X_4
Island control $\alpha(t)$
Output: Island detection
Find $\alpha(t)$ from `Algorithm 1`
while $\alpha(t) \neq 0$ **do**
  Find V variations
  for $P_{DG-1} \geq X_1$ *OR* $P_{DG-1} \leq X_2$ **do**
    Find $\Delta P/P$, $\Delta Q/P$
    Stop TEST condition
  end
  Repeat TEST condition of DG-2
end
Update P, Q and repeat the algorithm
Initiate the trip signal of ABEV in energy system.

gives the procedure of generating switching instants. Comparative analysis with latest research is presented in Table 1. In all comparative analysis, proposed technique

TABLE I
COMPARATIVE ANALYSIS WITH EXISTING METHODS.

S.No.	Parameter under study	Existed method	Propose method	Remark
1	State observer [4], [1]	Control of Grid-Tied Inverters	Both on and off grid	Two states of operation analysed
2	Distributed power [21]	AC Microgrids	AC and DC Microgrids	All MG and DG
3	Deep learning [11]	State estimation	Any system	FB-LOA system
4	Hybrid Deep learning [17]	Neural with optimal control	Grid control	control, grid control
5	Hybrid learning [9]	Data forecasting	Solar power	Solar DG
6	Off-Grid hybrid renewable [22]	Power control	DG	DG and inverter

is compare with all state-of-art reference. Each method gave the different techniques with parameter used in control. As per the each method of control, proposed FB-LOA made significant improvement in identification process of system operating state.

V. CONCLUSIONS

Proposed FB-LOA method is tested for islanding detection and successful events like NOEV, ABEV are also validated in electrical energy system. Observation ABEV operation from island control $\alpha(t)$, made the standard detection time for detection. Almost no mismatch event is recorded for wrong initiation of island detection using proposed FB-LOA method. During multiple DG units i.e. DG-1, DG-2 are integrated, FB-LOA method is tested successfully to initiate the trip signal during a island mode. Entire switching instants under testing is given in mismatch of P, Q events. Proposed method is compared with (i) AI based like ANN, FLC and ML; (ii) optimal control methods. Outcome of FB-LOA has been improved the detection time in every samples under testing of electrical energy system.

REFERENCES

[1] L. Guo et al., "A Virtual-Flux State Observer-Based Inductance Identification Method for Model Predictive Control of Grid-Tied Inverters With a Finite Phase Angle Set-Based PLL," IEEE Trans. Ind. Electron., vol. 70, no. 8, pp. 8009-8021, 2023.

[2] Y. Zhang, X. Li and A. Wu, "A Locust Recognition Method Based on Graph Convolution Neural Network," 2021 IEEE 4th Int. Conf. Computer and Communication Engg. Technology (CCET), Beijing, China, 2021, pp. 58-62.

[3] L Zhang, L P Ban, Y W You et al., "Locust outbreak and management [J]", J. Environ.l Entomology, vol. 42, no. 3, pp. 511-519, 2020.

[4] M. Abdelhamid, S. Kamel, L. Nasrat, H. Shahinzadeh and H. Nafisi, "Adaptive Coordination of Distance and Direction Overcurrent Relays in Active Distribution Networks Based on the Tunicate Swarm Algorithm," 2022 12th Smart Grid Conf. (SGC), Kerman, Iran, Islamic Republic of, 2022, pp. 1-6.

[5] Dorigo et al., Dorigo M., Birattari M., Stutzle T., "Ant colony optimization - artificial ants as a computational intelligence technique," IEEE Comput. Intell. Mag., pp. 28-39, 2006.

[6] Mucun Sun, Li He, Jie Zhang, "Deep learning-based probabilistic anomaly detection for solar forecasting under cyberattacks," Int. J. Electr. Power Energy Syst., Vol. 137, pp. 107752, 2022.

[7] Murli Manohar, Ebha Koley, Subhojit Ghosh, Dusmanta Kumar Mohanta, R.C. Bansal, "Spatio-temporal information based protection scheme for PV integrated microgrid under solar irradiance intermittency using deep convolutional neural network," Int. J. Electr. Power Energy Syst., vol. 116, pp. 105576, 2020.

[8] B. Su, Z. Zhou and H. Chen, "PVEL-AD: A Large-Scale Open-World Dataset for Photovoltaic Cell Anomaly Detection," IEEE Tran. Industr. Inform., vol. 19, no. 1, pp. 404-413, Jan. 2023.

[9] W. Liu, C. Ren and Y. Xu, "Missing-Data Tolerant Hybrid Learning Method for Solar Power Forecasting," *IEEE Trans. Sustain. Energy*, vol. 13, no. 3, pp. 1843-1852, July 2022.

[10] Cuevas, E., Fausto, F., González, A., "The Locust Swarm Optimization Algorithm. In: New Advancements in Swarm Algorithms: Operators and Applications," Intelligent Systems Reference Library, vol. 160. Springer, Cham., 2020.

[11] T. M. Hasan and J. Alneamy, "Medical Images Classification Using Hybrid Deep Learning CNN-PSO-GA," 2022 8th Int. Conf. Contemporary Information Technology and Mathematics (ICCITM), Mosul, Iraq, 2022, pp. 90-95.

[12] Shahrzad Saremi, Seyedali Mirjalili, Andrew Lewis, "Grasshopper Optimisation Algorithm: Theory and application," Adv. Eng. Softw., vol. 105, pp. 30-47, 2017.

[13] Murli Manohar, Ebha Koley, Subhojit Ghosh, Dusmanta Kumar Mohanta, R.C. Bansal, "Spatio-temporal information based protection scheme for PV integrated microgrid under solar irradiance intermittency using deep convolutional neural network," Int. J. Electr. Power Energy Syst., vol. 116, pp. 105576, 2020.

[14] H. M. Hasanien and M. Matar, "A Fuzzy Logic Controller for Autonomous Operation of a Voltage Source Converter-Based Distributed Generation System," IEEE Trans. Smart Grid, vol. 6, no. 1, pp. 158-165, 2015.

[15] Pener, Meir Paul; Simpson, Stephen J. "Locust Phase Polyphenism: An Update. Advances in Insect Physiology," Academic Press, 1st ed., vol. 36, pp. 9., sept. 2009.

[16] Mohammed Salem Binwahlan, Naomie Salim, Ladda Suanmali, "Fuzzy swarm diversity hybrid model for text summarization," Inform. Process. Manag., Vol. 46, no. 5, pp. 571-588, 2010.

[17] G. Yuan, B. Wang, B. Xue and M. Zhang, "Particle Swarm Optimization for Efficiently Evolving Deep Convolutional Neural Networks Using an Autoencoder-based Encoding Strategy," IEEE Trans. Evol. Compu, 2023.

[18] Cuevas, E., Fausto, F., González, A., “Locust Search Algorithm Applied to Multi-threshold Segmentation. In: New Advancements in Swarm Algorithms: Operators and Applications. Intelligent Systems,” Reference Library, Springer, Cham., vol .160., 2020

[19] Zhihong Ye, A. Kolwalkar, Yu Zhang, Pengwei Du and Reigh Walling, ”Evaluation of anti-islanding schemes based on nondetection zone concept,” in IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1171-1176, Sept. 2004.

[20] B. She et al., ”Decentralized and Coordinated V-f Control for Islanded Microgrids Considering DER Inadequacy and Demand Control,” IEEE Trans. Energy Convers., 2023.

[21] M. Jamali, H. R. Baghaee, M. S. Sadabadi, G. B. Gharehpetian and A. Anvari-Moghaddam, ”Distributed Cooperative Event-Triggered Control of Cyber-Physical AC Microgrids Subject to Denial-of-Service Attacks,” IEEE Trans. Smart Grid, 2023.

[22] N. A. Nuha, M. T. S. Injam and N. Chowdhury, ”Feasibility Analysis of Off-Grid Hybrid Renewable Energy for Rohingya Refugee in Bhasan Char,” 3rd Int. Conf. Robotics, Electrical and Signal Processing Techniques (ICREST), Dhaka, Bangladesh, 2023, pp. 133-137, 2023 .