# Teaching learning based optimization algorithm for effective analysis of power quality using dynamic voltage restorer

**Soumya Ranjan Das[1], Surender Reddy Salkuti[2]**
[1]Department of Electrical Engineering, Parala Maharaja Engineering College, Berhampur, India
[2]Department of Railroad and Electrical Engineering, Woosong University, Daejeon, Republic of Korea

**Article Info**

***Article history:***

Received May 28, 2024
Revised Oct 6, 2024
Accepted Nov 19, 2024

***Keywords:***

Dynamic voltage restorer
Harmonics estimation
Power quality
Voltage source inverter
Voltage swell

**ABSTRACT**

In this study, the load voltage is dynamically restored utilising the dynamic voltage restorer (DVR) using the voltage injection approach. The injected voltage is generated using a voltage-source inverter (VSI), which is necessary to correct for the utility network's sag and swell characteristics voltage. The restoration process is dependent on the condition and quality of the utility system, i.e., it injects energy into the external system for the duration of voltage sag, and during voltage swell, energy is absorbed by the compensator from the external system, causing an rise in dc link voltage, which is connected across the VSI. In this study two different controllers are employed based on a learning based optimized algorithm. The simulation results are shown using two different controllers and the performance of the proposed controller is found to be a better one.



***Corresponding Author:***

Surender Reddy Salkuti
Department of Railroad and Electrical Engineering, Woosong University
17-2, Jayang-Dong, Dong-Gu, Daejeon-34606, Republic of Korea
Email: surender@wsu.ac.kr

## 1. INTRODUCTION

Because of the widespread usage of non-linear loads by home and industrial customers, improving power quality (PQ) has become an essential concern in recent years [1]. Voltage quality problems [2], such as voltage sags or swells, are the most common in the network. These voltagerelated issues are caused by a variety of sources, including transmission system disturbances, defects in nearby feeders and fuses, and circuit breaker trips. Harmonic components in supply voltages occur as a result of uncompensated nonlinear loads in the utility system. Various gadgets have been developed to address these challenges in order to advance PQ. Conventionally, passive filters [3]-[5] were utilised, however due to various shortcomings [6], they have been replaced by active filters. A series compensator [7]-[9] which is also called as dynamic voltage restorer (DVR) is primarily used to improve PQ by reducing voltage sag andswell conditions. When compared to other custom-power devices in terms of technologicaladvancement and economic value, the DVR is the most effective in utility systems forimproving voltage quality [10]-[12]. To improve voltage quality, the DVR is implemented byinfusing voltages in series with the three-phase distribution system, resulting in voltagemagnitude and phase shift. The negative effects of voltage quality disruptions such as voltagesag and voltage swell are minimised by these devices. During a utility system outage, the DVR can help maintain voltage at a specific level by adding a compensating voltage [13] in series with the voltage across the load.

The demand across the load can be maintained by regulating the power supply from an energy storage device. With the impact of voltage sag, the energy storage device receives power from the utility system via the linked converters. Alternatively, high voltage swell might be harmful to equipment.

Practically, both voltage sag and swell occur concurrently. Furthermore, reactive power imbalances will consequence in overvoltage or swell in the utility network. Extreme and continuous overvoltage may cause harm to the storage device. This paper proposes a novel control mechanism for generating reference current that does not require reactive volt-amperes [14], [15]. To construct a signal, an actual calculation of its amplitude, frequency, and phase is necessary. The current approach is employed to produce the per unit component of the reference waveform for the HSAPF from the harmonic content signal. Compared to other conventional methods, like orthogonal component filter and least square error algorithms, Kalman-filter (KF) is known to be more resistant in noisy situations; thus, in the proposed study, KF is utilised to estimate per unit current reference [16].

The standard proportional-integral-derivative (PID) controller (PID) is less expensive, easy to tune, and but for complex cases, PID is not suitable to supply effective solutions. In such cases, a fuzzy logic controller (FLC) based PID is utilised because it improves performance by updating the PID controller's parameters on a frequent basis [17]-[20]. Again, one of the key benefits of adopting a fuzzy-based PID is that no mathematical formulation is required to select the membership function or the rule base. Generally, certain experiential guidelines are employed to choose the fuzzy constraints, which might not be the best values. As a result of the information presented above, the teaching learning based optimization algorithm (TLBOA) tunes the controller (PID and fuzzy PID) scaling factors to improve controller efficiency [21]-[23]. Therefore, in this study, TLBO-fuzzy PID (TLBOFPID) or TLBO-conventional PID (TLBOPID) is used to extract the reference maximum current as well as to manage the voltage of the inverter's DC link. Various instances are simulated to investigate the compensatory capacities of both TLBOFPID and TLBOPID-based HSAPF [24], [25].

## 2. SYSTEM ARCHITECTURE

Figure 1 depicts the configuration of the proposed system. A three-phase source is associated to a three-phase non-linear load. The non-linear load is designed to handle both balanced and unbalanced loads. Table 1 contains parameter values for both balanced and unbalanced loads. In this power system configuration, a DVR is fed at the point of common coupling (PCC), where it compensates for the load voltage, reduces harmonics [25], and maintains the DC link voltage. For harmonics estimation, two adaptive control approaches, TLBOPID and TLBOFPID are used.

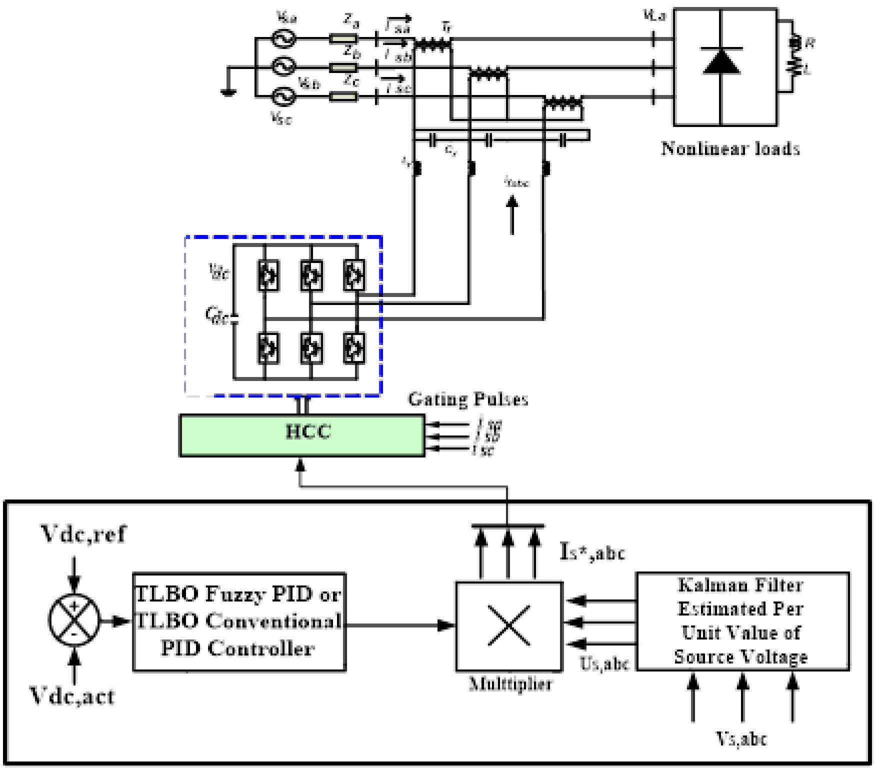



Figure 1. Configuration of the proposed model

Table 1. System-parameters

| Parameter | Values |
|---|---|
| Supply voltage | 220 V |
| Frequency | 50 Hz |
| Supply resistance and inductance | Rs =1 Ω and Ls=20 mH |
| Non-linear loads | 20 Kw |
| (balanced and unbalanced | R= 10 Ω and L= 50 mH |
| Sampling period | 50 µs |
| Dc link voltage | 200 V |
| Ripple filter | Rf=5 Ω, Cf= 10 µF, |
| PI gain | Kp=0.25, Ki=0.1 |

## 3. CONTROLLER STRATEGY

In this section, the reference current generation using KF and TLBO with PID and FPID are discussed in brief. TLBOA uses a revolutionary knowledge-based technique in which the instructor for the following iteration is chosen from among the previous best students [26]. In order to change the considered pupil's knowledge, the other pupils and their peers must then pick up knowledge from that student and share it with others. The avoidance of early or unexpected convergence and the preservation of multiplicity have made optimisation a popular field of study for many scholars in recent years. The two main stages in evolutionary processes are crossover and mutation, which are not established in TLBOA [27]. Teaching learning behaviour is the driving force behind TLBOA because it shares many characteristics with other evolutionary strategies. Every member of TLBOA has an adjustable search method based on its own learning.

### 3.1. Initialization

The initial population size i.e., [n×m] os created in this step, where the numbers of learners are represented by ‘ n ’ which is the size of population and the problem dimension is ‘ m ’ i.e. the subjects given. In the initial population matrix, the mark obtained by various learners in the jth subject is represented in the jth column.

$$Initial\ population\ X = \begin{bmatrix} x_{1,1} & x_{1,2} & \dots & x_{1,m} \\ x_{2,1} & x_{2,2} & \dots & x_{2,m} \\ . & . & & . \\ . & . & & . \\ x_{n,1} & x_{n,2} & \dots & x_{n,m} \end{bmatrix} \tag{1}$$

### 3.2. Teaching phase

The mean result of the class has to be improved by the teacher in the assigned subject in teacher phase. In this article, $X_{\mathrm{j,k,I}}$ is represented as the any value of solution where j (j=1,2,…,m) is the subject taken by the learner, k (k=1,2,…,n) is the learner itself and I represents the $i^{th}$ iteration. As the learner is taught by the teacher and is assumed to be the best solution $X_{\mathrm{j,kbest,I}}$ which will be the teacher in the next iteration. The average marks secured by the learner in each subject which is the average value of each column as given below where $y_j$ is the mark obtained by the learner in the $j^{th}$ subject.

$$M_{\mathrm{j,i}} = [y_1, \quad y_2, \quad \dots, \quad y_m] \tag{2}$$

The difference between the results obtained by the corresponding teacher with the mean result in that subject taught by the same teacher is written as:

$$\mathrm{Difference\_Mean}_{\mathrm{j,k,i}} = r_{\mathrm{j,i}}\left(X_{\mathrm{j,kbest,i}} - T_F M_{\mathrm{j,i}}\right) \tag{3}$$

Where $r_{\mathrm{j,I}}$ a random number is vary between 0 to1 and $T_F$ is the teaching factor taken 1 or 2.

$$T_F = \mathrm{round}[1 + \mathrm{rand}(0,1)] \tag{4}$$

Now, the existing population is to be updated is given as:

$$X'_{j,k,i} = X_{j,k,i} + \text{Difference\_Mean}_{j,k,i} \quad (5)$$

The well-run value of $X_{j,k,I}$ is accepted i.e. $X'_{j,k,i}$ only if $f(X'_{j,k,i}) < f(X_{j,k,I})$ else $X_{j,k,I}$ is accepted, where $f(X_{j,k,I})$ is the objective function.

### 3.3. Learning phase

In this phase, the learner has to improve based on the interactions with other students and if it has more knowledge than him, arbitrarily two learner P and Q are chosen so that $X'_{P,i} \neq X'_{Q,i}$.

$$X''_{j,P,i} = X'_{j,P,i} + r_{j,i}(X'_{j,P,i} - X'_{j,Q,i}) \text{ if } f(X'_{P,i}) < f(X'_{Q,i}) \quad (6)$$

$$X''_{j,P,i} = X'_{j,P,i} + r_{j,i}(X'_{j,Q,i} - X'_{j,P,i}) \text{ if } f(X'_{P,i}) > f(X'_{Q,i}) \quad (7)$$

Allow $X''_{j,P,I}$ if the performance is superior. Based on the above discussion, the flowchart of TLBOA is in Figure 2.

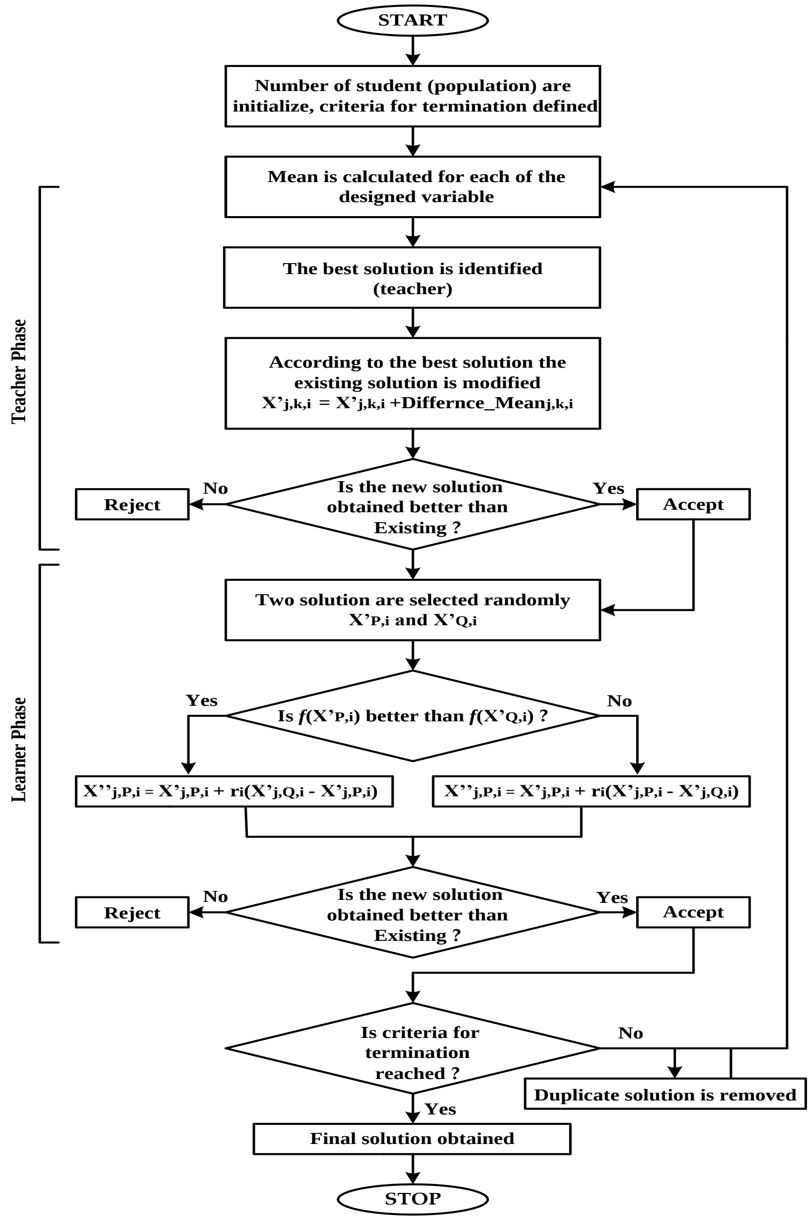



Figure 2. Flowchart of TLBOA

### 3.4. Objective function

Here, the objective function *J* of the integral time absolute error (ITAE) type is used. The objective function is thought to be modelled by the DC link capacitor voltage error [7]. The difference between the actual voltage and the DC link reference, or error *e(t)*, is what's being evaluated here, and minimising the error is the primary goal. For this goal function, a sudden increase or drop in load is taken into account.

$$J = \int_0^{tsim} t|e(t)|\, dt \quad (8)$$

## 4. RESULTS ANALYSIS

A power system model in MATLAB/Simulink is designed using the DVR, to assess how the suggested controller works in a three-phase system. In this system, the utility source, loads comprising both balanced and unbalanced and the DVR are connected. The injecting of compensating voltage through DVR are done using PID and FPID controllers through a learning based algorithm. Under balanced and unbalanced loads, the suggested TLBOFPID technique and the traditional TLBOPID technique are used to check the performance of the system. Subsequent subsections contain the relevant system parameters. The appendix contains the non-linear loads for balanced and unbalanced loads. When comparing the grid voltage to the typical sinusoidal voltage, distortion is evident. The non-linear load existence causes the grid voltage to exhibit sag and swell voltage characteristics. Figure 3 illustrates the simulated result. The whole voltage profile with sag and swell is displayed in Figure 3(a). Grid voltage with sag lasting 0.5–0.7 seconds is depicted in Figure 3(b), and a swell lasting 1.5–1.7 seconds is shown in Figure 3(c). Distortion in a normal fundamental wave is observed in the load voltage linked to the three-phase utility system. The total harmonic distortion (THD) is determined as 38.97% for unbalanced load. Relative figures are displayed in Figure 3(d). In order to enhance PQ and decrease harmonics, the power system is operated under DVR by utilising the TLBOPID and TLBOFPID harmonics estimation techniques. The performance are analysed under unbalanced load conditioning.

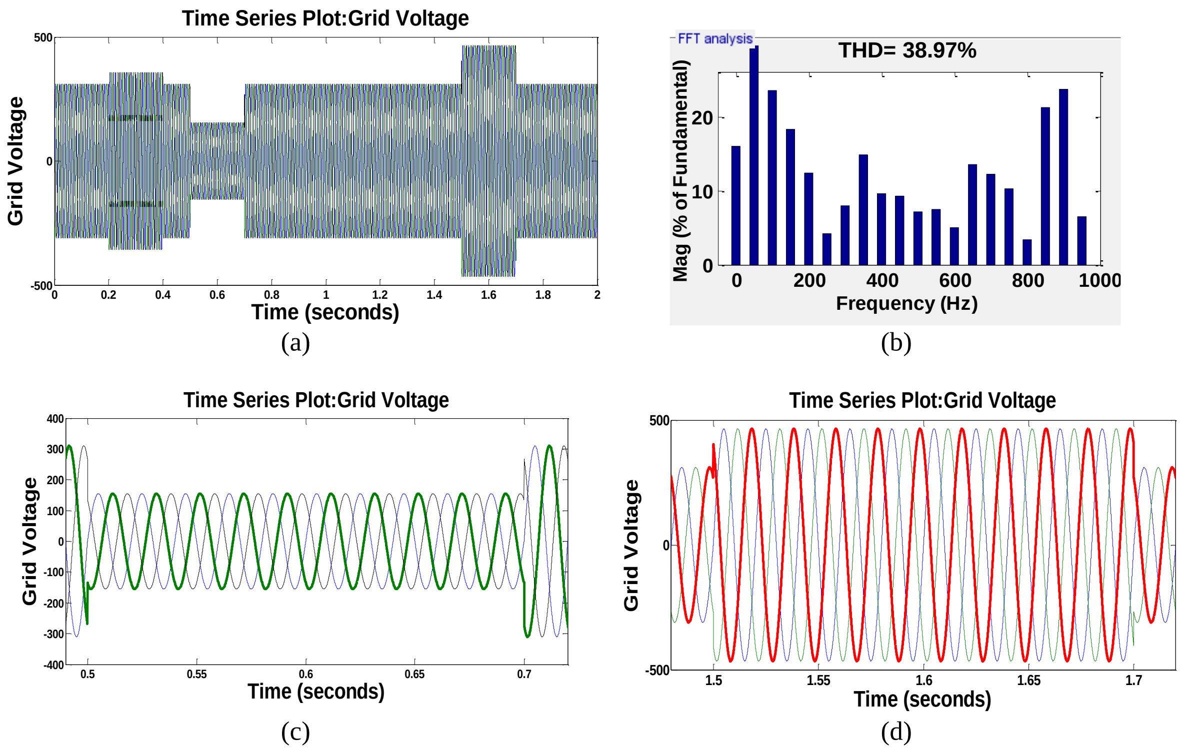
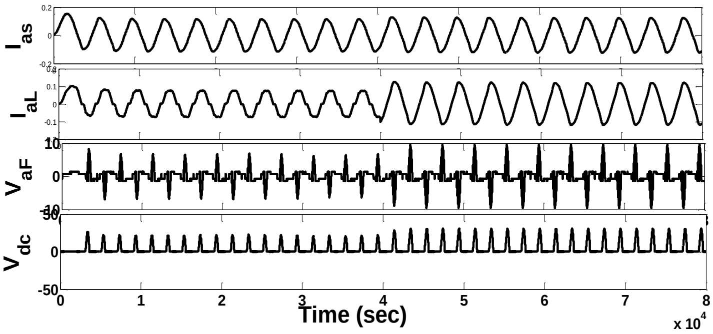


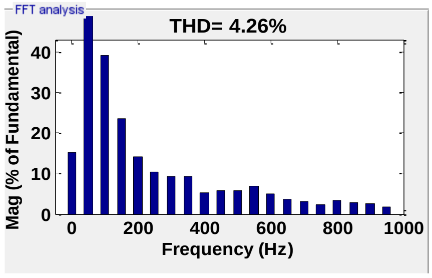

Figure 3. Simulated results of three phase grid system: (a) grid voltage showing sag and swell, (b) THD analysis of load voltage during unbalanced load, (c) grid voltage with voltage sag, and (d) grid voltage with voltage swell

### 4.1. Unbalanced-loading condition

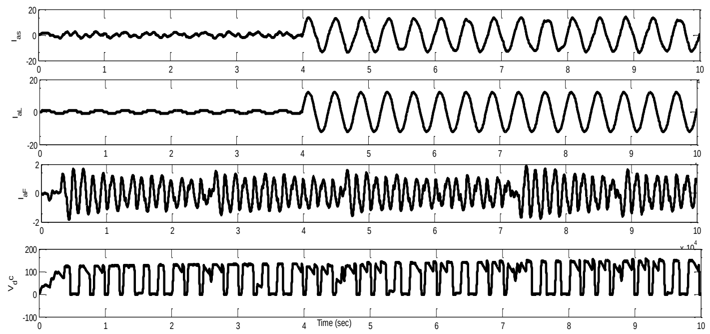
The DVR under imbalanced non-linear loading conditions is noticed in this subsection. In the first scenario, TLBOPID is used to run the system. Figure 4 displays the same results. Figure 4(a) produces the filter voltage, DC-link voltage, source and load currents. Figure 4(b) expresses the The THD value determined to be 4.26%. Additionally, the test is conducted utilising the TLBOFPID methodology. Figure 4(c) displays the results of the single-phase simulation for the source and load current, filter voltage, and DC-link voltage. Figure 4(d) displays the THD value was determined to be 3.72%. Based on the simulation results, it can be observed that the suggested TLBOFPID technique is used with the DVR to adjust for harmonic distortion with non-linear loads. It is observed that the TLBOFPID-based suggested model yields acceptable outcomes. Better DVR performance in these circumstances is implied by the THD of the load voltage.



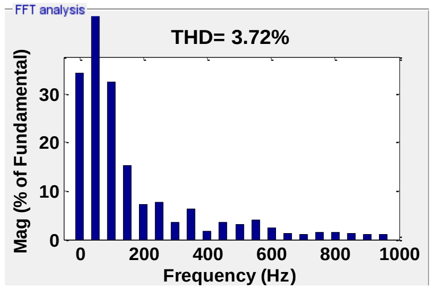

(a)




(b)




(c)




(d)

Figure 4. PQ improvement with unbalanced-load applying: (a) TLBOPID, (b) THD value using TLBOPID controller, (c) TLBOFPID, and (d) THD value using TLBOFPID controller

## 5. CONCLUSION

DVR has been proven to be the most practical, effective tool and commonly used device to improve the voltage profile and PQ of the system. The control circuit and power system model with a sensitive load is designed and simulated using MATLAB/Simulink tool. The proposed design is performed both with and without the DVR. The proposed DVR-based control approach produced a better and smooth voltage profile with very little harmonic content by compensating for the distorted load voltage. The performance of DVR is verified using different two different controllers PID and FPID based on teaching learning optimization techniques. By employing the TLBOPID and TLBOFPID methods to estimate the load voltage and perform DVR control, the error of voltage injection has been minimised. The THD value of TLBOFPID is 3.72% and found to be satisfactory compared to TLBOPID having THD 4.26%. Therefore, on load voltage compensation, the TLBOFPID technique is found to be satisfactory. Further, future scope of DVR can be engaged in different sophisticated semiconductor devices or loads which require harmonics less and reliable power supply using different soft computing approaches.

## ACKNOWLEDGEMENTS

This research work was supported by "Woosong University's Academic Research Funding - 2025".

## REFERENCES


[1] S. R. Das *et al.*, “A comprehensive survey on different control strategies and applications of active power filters for power quality improvement,” *Energies*, vol. 14, no. 15, p. 4589, Jul. 2021, doi: 10.3390/en14154589.

[2] S. R. Das, P. K. Ray, and A. Mohanty, “Power quality improvement using grid interfaced PV with multilevel inverter based hybrid filter,” in *2018 1st International Conference on Advanced Research in Engineering Sciences (ARES)*, Jun. 2018, pp. 1–6, doi: 10.1109/ARESX.2018.8723281.

[3] R. Beres, X. Wang, F. Blaabjerg, C. L. Bak, and M. Liserre, “A review of passive filters for grid-connected voltage source converters,” in *2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014*, Mar. 2014, pp. 2208–2215, doi: 10.1109/APEC.2014.6803611.

[4] A. M. Zobaa, S. H. E. Abdel Aleem, and H. K. M. Youssef, “Comparative analysis of double-tuned harmonic passive filter design methodologies using slime mould optimization algorithm,” in *2021 IEEE Texas Power and Energy Conference (TPEC)*, Feb. 2021, pp. 1–6, doi: 10.1109/TPEC51183.2021.9384950.

[5] T. K. Panigrahi, S. R. Das, and R. Tripathy, “Power quality improvement using different control techniques in hybrid filters,” in *2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP)*, Jul. 2022, pp. 1–5, doi: 10.1109/ICICCSP53532.2022.9862354.

[6] S. R. Das, P. K. Ray, and D. P. Mishra, “Power quality improvement using hybrid filters based on artificial intelligent techniques,” in *Intelligent Technologies: Concepts, Applications, and Future Directions, Volume 2*, Springer Nature Singapore, 2023, pp. 165–186.

[7] B. Panda, M. Padhy, S. R. Das, and S. Rout, “Application of adaptive filters in dynamic voltage restorer for power system harmonics estimation,” in *2022 IEEE 2nd International Symposium on Sustainable Energy, Signal Processing and Cyber Security (iSSSC)*, Dec. 2022, pp. 1–6, doi: 10.1109/iSSSC56467.2022.10051299.

[8] A. Moghassemi and S. Padmanaban, “Dynamic voltage restorer (DVR): a comprehensive review of topologies, power converters, control methods, and modified configurations,” *Energies*, vol. 13, no. 16, p. 4152, Aug. 2020, doi: 10.3390/en13164152.

[9] R. Pal and S. Gupta, “Topologies and control strategies implicated in dynamic voltage restorer (DVR) for power quality improvement,” *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, vol. 44, no. 2, pp. 581–603, Jun. 2020, doi: 10.1007/s40998-019-00287-3.

[10] A. Farooqi, M. M. Othman, M. A. M. Radzi, I. Musirin, S. Z. M. Noor, and I. Z. Abidin, “Dynamic voltage restorer (DVR) enhancement in power quality mitigation with an adverse impact of unsymmetrical faults,” *Energy Reports*, vol. 8, pp. 871–882, Apr. 2022, doi: 10.1016/j.egyr.2021.11.147.

[11] P. Roncero-Sanchez, E. Acha, J. E. Ortega-Calderon, V. Feliu, and A. Garcia-Cerrada, “A versatile control scheme for a dynamic voltage restorer for power-quality improvement,” *IEEE Transactions on Power Delivery*, vol. 24, no. 1, pp. 277–284, Jan. 2009, doi: 10.1109/TPWRD.2008.2002967.

[12] A. H. Soomro, A. S. Larik, M. A. Mahar, A. A. Sahito, A. M. Soomro, and G. S. Kaloi, “Dynamic voltage restorer-a comprehensive review,” *Energy Reports*, vol. 7, pp. 6786–6805, Nov. 2021, doi: 10.1016/j.egyr.2021.09.004.

[13] M. Farhadi-Kangarlu, E. Babaei, and F. Blaabjerg, “A comprehensive review of dynamic voltage restorers,” *International Journal of Electrical Power & Energy Systems*, vol. 92, pp. 136–155, Nov. 2017, doi: 10.1016/j.ijepes.2017.04.013.

[14] A. K. Mishra, S. R. Das, P. K. Ray, R. K. Mallick, A. Mohanty, and D. K. Mishra, “PSO-GWO optimized fractional order PID based hybrid shunt active power filter for power quality improvements,” *IEEE Access*, vol. 8, pp. 74497–74512, 2020, doi: 10.1109/ACCESS.2020.2988611.

[15] R. Zhao, Q. Li, H. Xu, Y. Wang, and J. M. Guerrero, “Harmonic current suppression strategy for grid-connected PWM converters with LCL filters,” *IEEE Access*, vol. 7, pp. 16264–16273, 2019, doi: 10.1109/ACCESS.2019.2893226.

[16] W. Xu, C. Huang, and X. Xie, “Analysis and application of Taylor-Kalman filters under a distorted grid condition,” *IEEE Access*, vol. 8, pp. 106822–106831, 2020, doi: 10.1109/ACCESS.2020.3000258.

[17] M. Badoni, A. Singh, and B. Singh, “Adaptive neurofuzzy inference system least-mean-square-based control algorithm for DSTATCOM,” *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, pp. 483–492, Apr. 2016, doi: 10.1109/TII.2016.2516823.

[18] A. K. Mishra, P. K. Ray, A. K. Patra, R. K. Mallick, S. R. Das, and R. Agrawal, “Harmonic and reactive power compensation using hybrid shunt active power filter with fuzzy controller,” in *Intelligent and Cloud Computing: Proceedings of ICICC 2019, Volume 1*, Springer, 2021, pp. 533–545.

[19] P. K. Ray, S. R. Paital, A. Mohanty, F. Y. S. Eddy, and H. B. Gooi, “A robust power system stabilizer for enhancement of stability in power system using adaptive fuzzy sliding mode control,” *Applied Soft Computing*, vol. 73, pp. 471–481, Dec. 2018, doi: 10.1016/j.asoc.2018.08.033.

[20] S. Das and I. Pan, “On the mixed $H_2/H_\infty$ loop-shaping tradeoffs in fractional-order control of the AVR system,” *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, pp. 1982–1991, Nov. 2014, doi: 10.1109/TII.2014.2322812.

[21] S. Ahmadi, D. A. Haghighi, M. Kheyrdoust, F. Dini, and K. Nasim, “The application of optimum self-tuning fuzzy logic controllers in multi-area power systems including UPFC,” in *2020 IEEE 18th World Symposium on Applied Machine Intelligence and Informatics (SAMI)*, Jan. 2020, pp. 187–194, doi: 10.1109/SAMI48414.2020.9108721.

[22] R. Pilla, A. T. Azar, and T. S. Gorripotu, “Impact of flexible AC transmission system devices on automatic generation control with a metaheuristic based fuzzy PID controller,” *Energies*, vol. 12, no. 21, p. 4193, Nov. 2019, doi: 10.3390/en12214193.

[23] M. Zhang, L. Jiao, R. Shang, X. Zhang, and L. Li, “Unsupervised EA-based fuzzy clustering for image segmentation,” *IEEE Access*, vol. 8, pp. 8627–8647, 2020, doi: 10.1109/ACCESS.2019.2963363.

[24] P. K. Ray, S. R. Das, and A. Mohanty, “Fuzzy-controller-designed-PV-based custom power device for power quality enhancement,” *IEEE Transactions on Energy Conversion*, vol. 34, no. 1, pp. 405–414, Mar. 2019, doi: 10.1109/TEC.2018.2880593.

[25] P. Salmeron and S. P. Litran, “Improvement of the electric power quality using series active and shunt passive filters,” *IEEE Transactions on Power Delivery*, vol. 25, no. 2, pp. 1058–1067, Apr. 2010, doi: 10.1109/TPWRD.2009.2034902.

[26] D. P. Mishra, K. K. Rout, S. Mishra, M. Nivas, R. K. P. R. Naidu, and S. R. Salkuti, “Power quality enhancement of grid-connected PV system,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 1, pp. 369–377, Mar. 2023, doi: 10.11591/ijpeds.v14.i1.pp369-377.

[27] P. Ray and S. R. Salkuti, “Smart branch and droop controller based power quality improvement in microgrids,” *International Journal of Emerging Electric Power Systems*, vol. 21, no. 6, Dec. 2020, doi: 10.1515/ijeeps-2020-0094.

**BIOGRAPHIES OF AUTHORS**

**Soumya Ranjan Das** completed his Ph.D. in the area of power quality and artificial intelligence (AI)-controlled techniques in 2021 from the Department of Electrical Engineering, International Institute of Information and Technology (IIIT) Bhubaneswar. He works with the Department of Electrical Engineering, Parala Maharaja Engineering College, Berhampur. He has received the BPUT foundation day research award in 2023. His research interests include power quality, power converters, soft computing-based harmonics reduction, and robust and adaptive control techniques in grid-interactive renewable systems. He can be contacted at email: soumyaranjan.ee@pmec.ac.in.

**Surender Reddy Salkuti** received Ph.D. degree in electrical engineering from the Indian Institute of Technology (IIT), New Delhi, India, in 2013. He was a Postdoctoral Researcher at Howard University, Washington, DC, USA, from 2013 to 2014. He is currently an Associate Professor at the Department of Railroad and Electrical Engineering, Woosong University, Daejeon, Republic of Korea. His current research interests include market clearing, including renewable energy sources, demand response, and smart grid development with the integration of wind and solar photovoltaic energy sources. He can be contacted at email: surender@wsu.ac.kr.