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Advanced DVR and Strategic BESS Arrangement for Superior Voltage Sag Mitigation in Distribution Networks

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Abstract: **-** Increased integration of short circuit faults created disturbances in the distribution system with the number of voltage generation profiles in the system, making voltage regulation a tedious task. However, the DVR brings an opportunity to solve these issues, as they can provide renewable local energy and also act as voltage regulation components in the network. In this paper, an optimized DVR and an optimally placed BESS framework are used to overcome voltage-sag and voltage-swell problems S-OOA optimizes DVR, through ideal parameter tuning of PID controllers, this improved the steady state response of DVR. BESS is optimally located using HGJHA by analyzing the most frequent voltage dips. By integrating this DVR and the BESS the voltage support capabilities were increased, and power quality and voltage stability were also increased. By implementing and evaluating the proposed model in MATLAB/Simulink, it shows better power quality of up to 95%. which outperforms previous approaches.

Keywords: *Voltage sag, Distributed Voltage Regulator (DVR), Self-Adaptive learning -Osprey Optimization Algorithm (S-OOA), Hybrid Golden Jackal- Hippopotamus algorithm (HGJHA) and BESS*

1. Introduction

Voltage sag in electric lines causes multiple disturbances when not declared properly. This creates a hectic in Radial Distribution Network (RDN) (Pompodakis et al., 2024). RDN remains a general practice of electric power distribution to deliver power at the custom end. This was mainly based on the radial feeder section in RDN and it also forms the Distributed Sub Station (DSS) (Dudi & Sharma, 2024). Without any failures in the feeder section and distributer substation which leads to customer interruptions. This interruption needs to be properly declared; these interruptions were of two types namely voltage sag and swell(Rezaei et al., 2024). The voltage sag means there will be a decrease between 0.1 and 0.9 Root Mean Square (RMS) voltage or else the current value at power frequency will be between 0.5 cycle up to 1 minute. Subsequently voltage swell of the network occurs when there is an increase in RMS voltage between 1.1 to 1.8 or else the current at power frequency ranges between 0.5 cycle to 1 minute. Both these Voltage sag and swell need to be compensated for uninterrupted services at the grid. This may occur at different stages of the network such as between supply

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and bus or between load and bus etc., Prediction and treatment of these sag/swell is a major issue (E. Z. M. Mattar et al., 2024). (Ikram et al., 2024)

Most of the works use RDN for simple fault detection purposes, but still, there are notable reliability issues, limited redundancy, and voltage regulation (Kiranmai & Laxmi, 2023). This needs to be rectified. For this rectification purpose, a Dynamic Voltage Restorer (DVR) has been used, DVR is mainly introduced to protect the electrical pieces of equipment from voltage sag/swells. By injecting voltage into the network, this DVR tries to compensate for the drops or rises in the supply voltage(Soni & Fernandez, 2024) . The better achievement was noted when the DVR was connected in series with load. DVR consists of components such as Converters, Batteries, and control systems (Setty et al., 2023). The converters used in DVR require a controller such as PI, PID, POD, and FOPID controllers. Among these PI controllers are feasible, as they continuously measure the output voltage of the system. computes errors and adjusts the actuator device. Tuning of this PI controller needs to be focused to improve the performance. Likewise, one more piece of equipment is a battery energy storage system (BESS). BESS stores energy during low demand and supplies during high demand. It consists of anode, cathode, electrolyte, and electrochemical cells. BESS can withstand the supply until needed. Placement of this BESS in the network is a difficult task (Klemets & Degefa, 2023).(Mohamed El-Saeed et al., 2023)

Previously number of methods, approaches, and techniques were proposed to make correct implications on sag/swell under various circumstances (Salimon et al., 2023). Some of the approaches used different controllers to select proper tuning parameters and optimize the performance but failed to focus on mitigation time and response time (Majumder et al., 2023). On the other hand, some approaches focused on the placement of capacitors, these approaches use machine learning approach, but are still unable to reach a satisfactory result (E.-Z. M. Mattar et al., 2023). Further, some approaches are used to optimize the performance of DVR by taking multiple indexes as objective and optimizing them using different optimization algorithms namely pelican optimization, Kepler optimization, and Harris hawk optimization. But still, they focused only on sag and also lacked stability (Tan et al., 2023)(Rawa et al., 2023). Some techniques were introduced for the appropriate placement of BESS, but these techniques were not suitable for real-time updates. Hence, to overcome all these issues a novel model has been proposed in this study.

2. Objectives

- Previously there was a smaller number of solutions were given to predict both voltage sags and placement of BESS in most required spots in the network.

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- Prioritizing the spots based on their previous voltage dips and also spots that are close to vital loads were not considered in any of the previous works.
- Failure of any components in a DVR such as the converter can create great failure that affects the entire system functionality, also using control algorithms for DVRs remains complex.
- The performance of a DVR is limited by the capacity of its energy storage system. During prolonged voltage sags or swells, the stored energy may be insufficient to maintain voltage levels.
- Focusing on these problems a novel model has been proposed that can predict issues in the network and solve them using optimization algorithms.

3. Methods

This paper proposes an optimized DVR and battery energy storage systems (BESSs) framework for voltage-sag and voltage-deviation problems in distribution networks and its architecture in Figure 1.

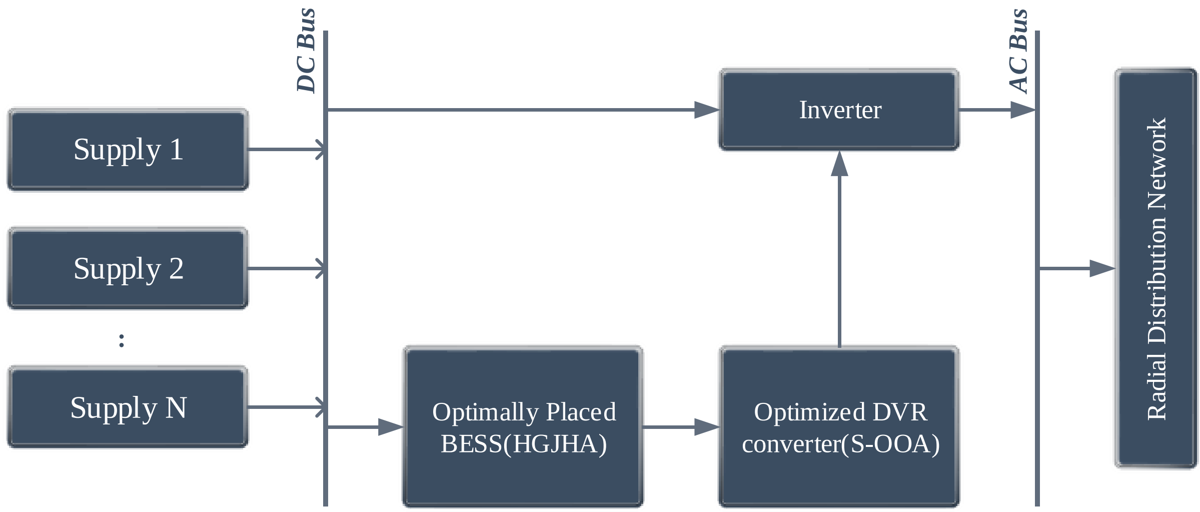

Figure 1: Block diagram of the proposed model

The flow diagram of the proposed Hybrid Golden Jackal- Hippopotamus algorithm (HGJHA) is shown in figure 2.

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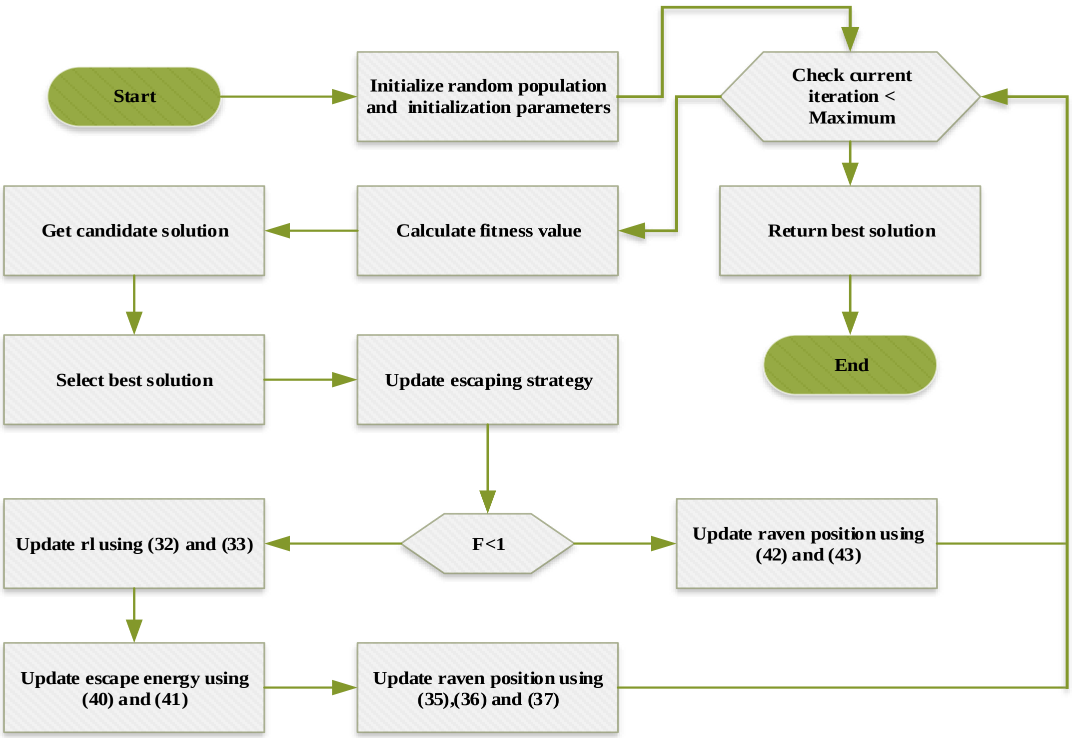

Figure 2: Flow diagram of HGJHA

Proposed model is implemented with Radial Bus 14 distribution system and compared with previous established methods. The results show that the proposed method is far better than previous models proposed in terms of power quality, voltage stability and voltage supply quality.

The simulation/MATLAB model of the proposed model is shown in figure 3,4 and 5.

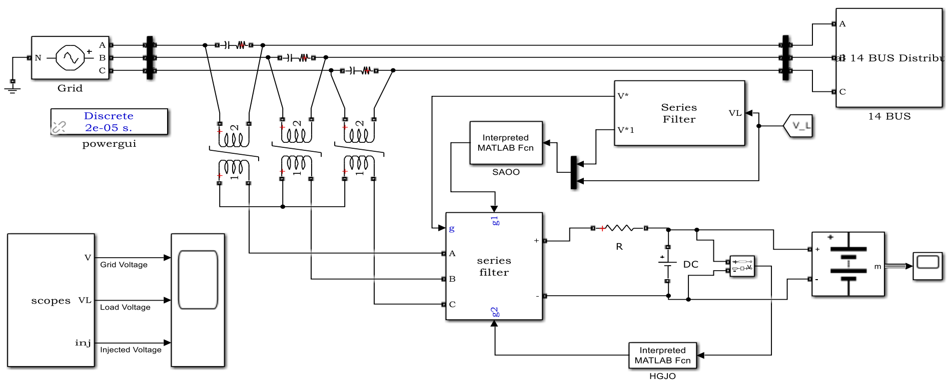

Figure 3: Overall proposed simulation model

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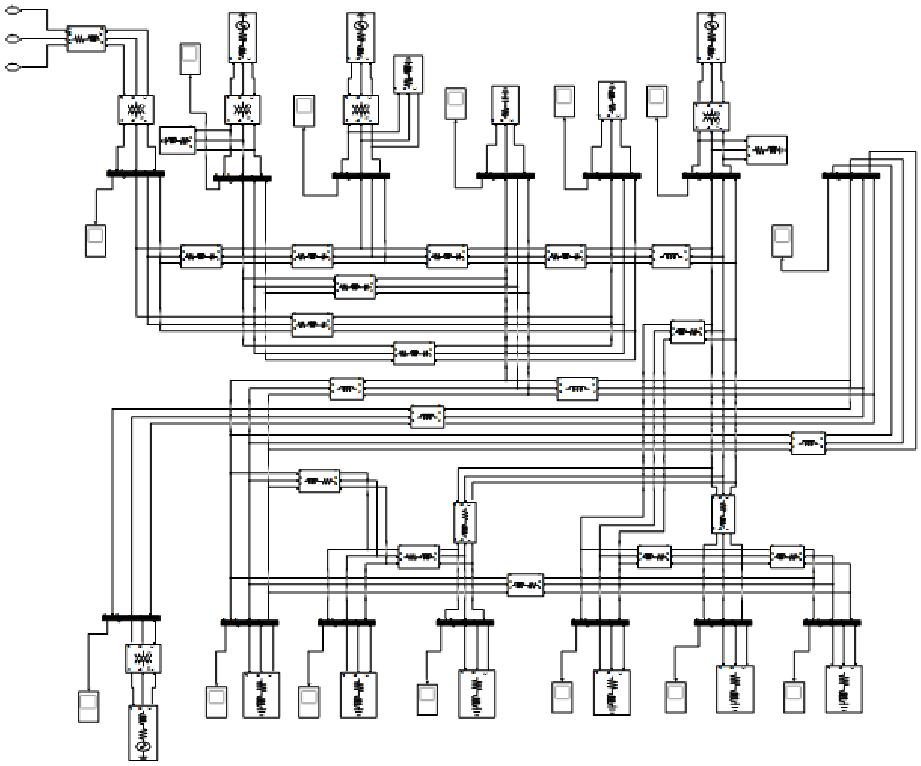

Figure 4: Radical bus 14 system

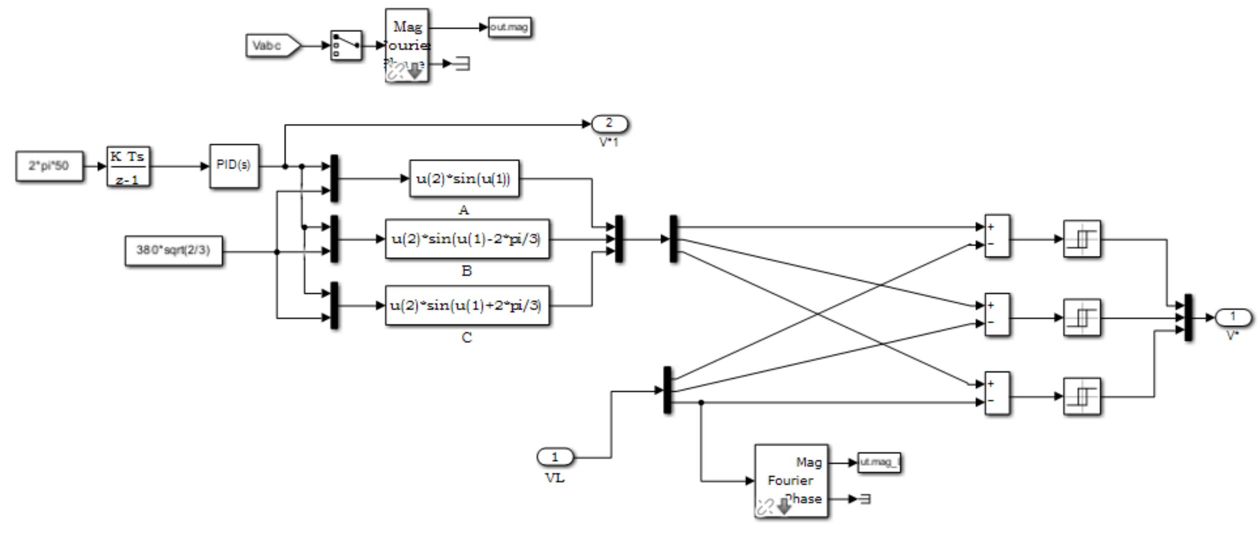

Figure 5: DVR

4. Results

Voltage profile results for compensated and uncompensated in distribution line

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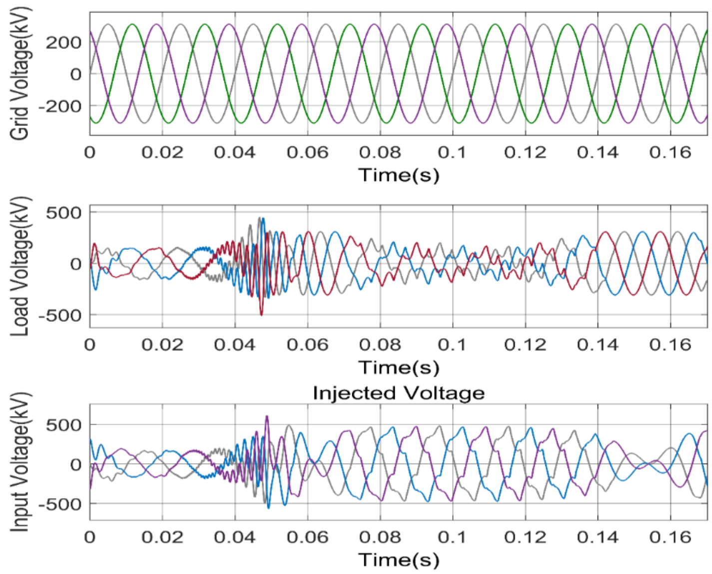

Figure 6: Per unit voltage measurement during compensation

Figure 6, clearly shows that the simulation results of balanced three phase loads in radial distribution network in the presence of DVR and BESS. The voltage waveforms were generated when optimized DVR and Optimally placed BESS was there in the network model. It was observed that at distributer feeder time length of up to 0.16 seconds were monitored. The voltage profile reaching the distributer feeder end within a standard permissible voltage range of 5% with nominal voltage value was noted. As the phase voltages were not equal this means that there were no interruptions for end users.

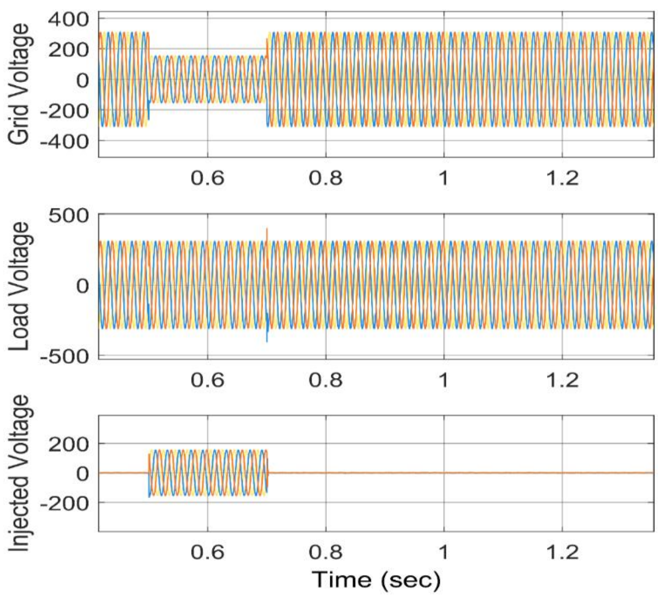

Figure 7: Per unit voltage during sag compensation

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Figure 7 depicts a situation where a voltage sag occurred in the network, exceeding the minimum allowable standard of IEEE, leading to unsatisfactory voltage quality for the customer end as indicated at that point. A simulation is once again performed with DVR in place for an unbalanced 3-phase load in the secondary distribution network. The voltage waveforms obtained were found to be in the standard allowable voltage range of 0.95 p.u to 1.05 p.u of the nominal voltage. All three phase voltages have the same magnitude and the phase angle and frequency shifts are within legal limits.

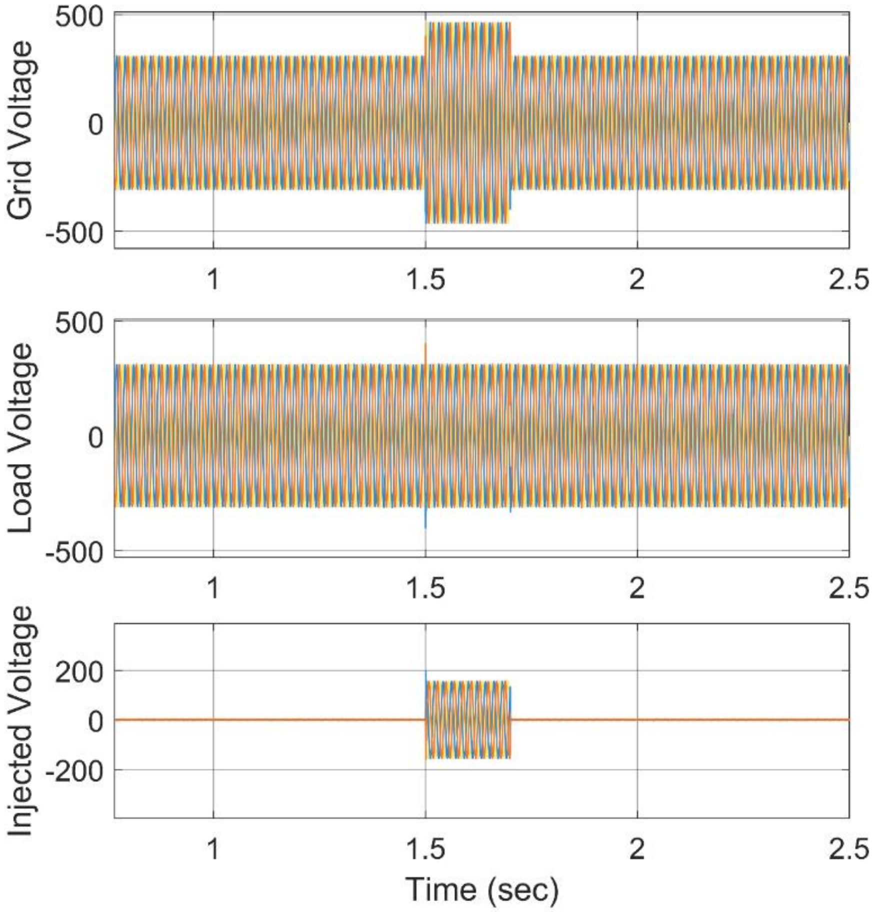

Figure 8: Per unit voltage during swell compensation

Figure 8 illustrates that the per unit voltage of the swell compensation ranges from 1 to 2.5 over a period of time. After compensation with the injected voltage from DVR, the load voltage profile on all 3 phases returns to its normal 1.0 p.u value. This demonstrates that the control scheme design for DVR is successful and productive as it fulfills its intended purpose.

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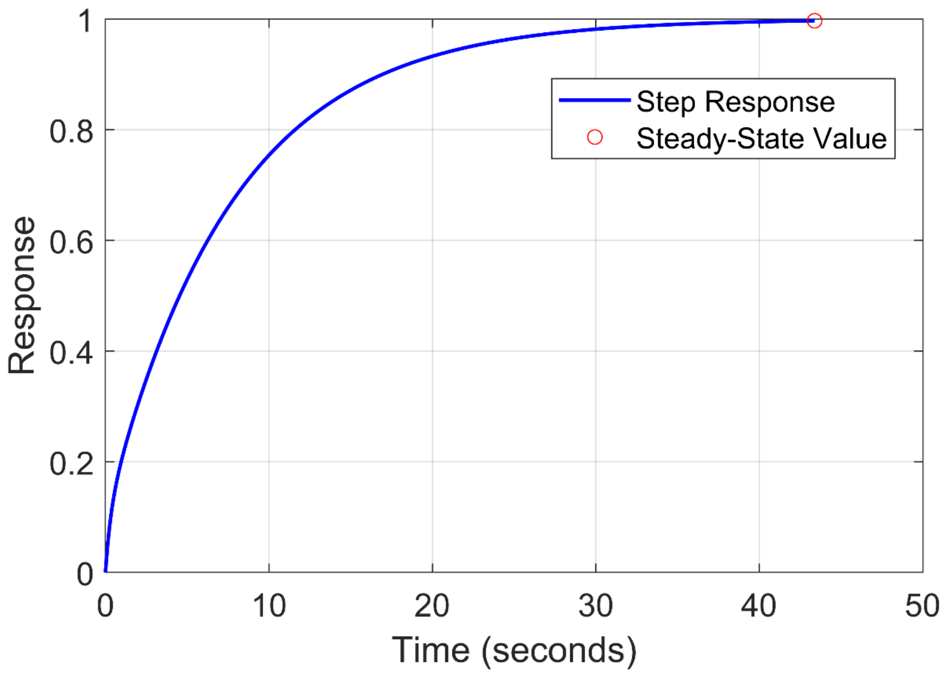

Figure 9: Response time Vs time graph

Figure 9 shows the Steady state response obtained for the PI controller used to optimize DVR converter in the proposed model. It was clearly visible that due to the use of S-OOA in DVR, the steady state response of PI was reached at a step response of 48 seconds which was far better than original PI controller response.

5. Discussion

In this study, an optimized DVR and Optimally placed BESS has been developed and implemented for stabilizing the polluted grid voltage and obtained a better three-phase balanced load voltages as output. A traditional PI controller, for DC bus voltage stabilization and compensation along with S-OOA optimization algorithm has been initially proposed. A poor stabilization was improved but in the other hand, an alternative supply is required. For this purpose, HGJHA with BESS has been proposed. Indexes of BESS are taken and the minimum loss spots are selected and BESS were placed. This improved the step response of the system and also improved the compensation stability. DVR is taking less than half cycle to compensate using the proposed control algorithm. Moreover, this fluctuation is compared with established algorithms. In this model LMS of the model was not focused, in future model can be developed focused on stabilizing compensation with three objectives.

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Refrences

[1] Arya, S. R., Mistry, K. D., & Kumar, P. (2024). DVR Using Randomized Self-Structuring Fuzzy and Recurrent Probabilistic Fuzzy Neural-Based Controller. Journal of The Institution of Engineers (India): Series B. https://doi.org/10.1007/s40031-023-00973-1

[2] Dudi, K., & Sharma, N. (2024). Integration of Energy Storage Systems in Radial Distribution Networks for Enhanced Reliability and Efficiency. In Acta Energetica (Vol. 1). http://actaenergetica.org

[3] Goud, B. S., Kumar, M. K., Kumar, N. A., Kalyan, C. N. S., Bajaj, M., Choudhury, S., & Shukla, S. (2023). Dynamic Voltage Restorer to Mitigate Voltage Sag/Swell using Black Widow Optimization Technique with FOPID Controller. EAI Endorsed Transactions on Energy Web, 10. https://doi.org/10.4108/EW.4331

[4] Ikram, S., Rehman, K., Altamash, M., & Miraj, J. (2024). Design of Radial Distribution System to Study Load-Flow and Short Circuit Analysis Using ETAP Software. Pakistan Journal of Engineering and Technology, 7(01), 42–49. https://doi.org/10.51846/vol7iss01pp42-49

[5] Khalghani, M. R., Shamsi-nejad, M. A., & Khooban, M. H. (2014). Dynamic voltage restorer control using bi-objective optimisation to improve power quality's indices. IET Science, Measurement and Technology, 8(4), 203–213. https://doi.org/10.1049/iet-smt.2013.0084

[6] Kiranmai, S. A., & Laxmi, A. J. (2023). Biogeography Based Optimization for Enhancing Dynamic Performance of Dynamic Voltage Restorer in Mitigating Power Quality Problems (pp. 537–547). https://doi.org/10.2991/978-94-6463-252-1_56

[7] Vamshi Krishna, D., & Reddi Khasim, S. (2023). VOLTAGE SAG MITIGATION IN ON-GRID HYBRID POWER SYSTEM USING BATTERY AND SMES BASED MULTI-LEVEL DVR. In Dogo Rangsang Research Journal UGC Care Group I Journal (Vol. 13, Issue 2).

[8] A. F. S., Seini, T., Ayasu, B., & Nyantakyi, E. A. (2024). Enhancing Reactive Power Compensation in Distribution Systems through Optimal Integration of D-STATCOM using the Pelican Optimization Algorithm (Vol. 7, Issue 1).

[9] Rezaei, M. F., Gandomkar, M., & Nikoukar, J. (2024). Optimizing Multi-objective Function for User-Defined Characteristics Relays and Size of Fault Current Limiters in Radial Networks with Renewable Energy Sources. Journal of Operation and Automation in Power Engineering, 12(1), 42–53. https://doi.org/10.22098/JOAPE.2022.10582.1757

[10] Pompodakis, E. E., Katsigiannis, Y. A., & Karapidakis, E. S. (2024). Optimizing Fault Ride-Through of DGs in Distribution Networks to Preserve Recloser-Fuse

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Coordination. IEEE Access, 12, 31228–31242. https://doi.org/10.1109/ACCESS.2024.3369892

[11] Naidu, T. A., Arya, S. R., Maurya, R., Singh, B., & Al-Durra, A. (2020, October 10). Combined Variable Step Size LMS for DVR with Error Regulator Gain Tuning through Ant-Lion Optimization. 2020 IEEE Industry Applications Society Annual Meeting, IAS 2020. https://doi.org/10.1109/IAS44978.2020.9334758

[12] Mohamed El-Saeed, M. A. E. sayed, Abdel-Gwaad, A. F., & Farahat, M. A. E. fattah. (2023). Solving the capacitor placement problem in radial distribution networks. Results in Engineering, 17. https://doi.org/10.1016/j.rineng.2022.100870

[13] Mattar, E.-Z. M., Mahmoud, E. S., & El-Sayed, M. I. (2023). POWER QUALITY IMPROVEMENT CONSIDERING VOLTAGE SAG AND UNBALANCE USING DVR باستخدام الجهد اتزان وعدم الجهد انخفاض االعتبار فى ألاخذ مع الكهربية القدرة جودة تحسين مسترجع In Journal of. الجهد الديناميكى 2 السيد ابراهيم محمد ، 1 محمود سعد اكرامى ، 1* محمد محمود الزهراء Al-Azhar University Engineering Sector (Vol. 18, Issue 66)

[14] Mattar, E. Z. M., Mahmoud, E. S., & El-Sayed, M. I. (2024). Mitigation of voltage sag and voltage swell by using dynamic voltage restorer. International Journal of Power Electronics and Drive Systems, 15(2), 1290–1299. https://doi.org/10.11591/ijpeds.v15.i2.pp1290-1299

[15] Majumder, S., Vosughi, A., Mustafa, H. M., Warner, T. E., & Srivastava, A. K. (2023). On the Cyber-Physical Needs of DER-Based Voltage Control/Optimization Algorithms in Active Distribution Network. In IEEE Access (Vol. 11, pp. 64397–64429). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2023.3278281

[16] Kumar, P., & Arya, S. R. (2023). Performance evaluation of dynamic voltage restorer using intelligent control algorithm. E-Prime - Advances in Electrical Engineering, Electronics and Energy, 6. https://doi.org/10.1016/j.prime.2023.100382

[17] Klemets, J. R. A., & Degefa, M. Z. (2023). A Distributed Algorithm for Controlling Continuous and Discrete Variables in a Radial Distribution Grid. IEEE Access, 11, 2488–2499. https://doi.org/10.1109/ACCESS.2023.3234102

[18] Naidu, T. A., Arya, S. R., Maurya, R., & Rajgopal, V. (2020). Compensation of voltage-based power quality problems using sliding mode observer with optimised PI controller gains. IET Generation, Transmission and Distribution, 14(14), 2656–2665. https://doi.org/10.1049/iet-gtd.2019.1623