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Optimum control for dynamic voltage restorer based on particle swarm optimization algorithm

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ABSTRACT

This article addresses a variety of power quality concerns, including voltage sag and swell, surges, harmonics, and so on, utilizing a dynamic voltage restorer (DVR). The proposed controller for DVR is proportional plus integral (PI) controller. Two methods are used for tuning the parameters of PI controller, trial and error and intelligent optimal method. The utilized optimal method is particle swarm optimization (PSO) method. Results depicted that DVR using PI controller tuned by PSO has improved performance than PI controller tuned by trial and error in term of rise time, maximum overshoot and settling time, as well as total harmonic distortion (THD). These improvements are applicable for voltage sag and swell conditions.

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1. INTRODUCTION

In manufacturing distribution networks, voltage fluctuations are the most prevalent problem with voltage stability. Voltage sags, swells, harmonics, destabilizes, and flashes are the most common voltage disruptions. These disruptions may cause voltage-sensitive components in companies, offices, and institutions to fail, as well as severe operational interruptions that lead to significant financial and/or information loss. The term "voltage sag" refers to a brief drop in root mean square (RMS) AC voltage (10%-90% of voltage level) with an operating frequency ranging between 0.5 cycles to a few seconds [1], [2]. Various solutions have been introduced and used in reality to lessen the effects of voltage and power quality disturbances on the network. To mitigate the voltage differential between normal and disrupted operation situations, devices including distribution static compensator (D-STATCOM), solid state transformer (SST), uninterruptible power supply (UPS), and dynamic voltage restorer (DVR) are employed. Due to its improved performance compared to other technologies, the DVR is regarded as the perfect option for minimizing voltage sag and swell between all equipment. Furthermore, in comparison to other equipment, DVR is the more cost-effective option [3], [4]. Fault condition disruptions can cause sensitive devices to fail or shut down, as well as an imbalanced high current that can blow fuses or trip breakers. Such faults may cost the client a lot of money, ranging from minor quality alterations to device damage and productivity delays [5]. Voltage quality concerns are extremely sensitive to susceptible loads access to the power supply. Just a little voltage difference might cause catastrophic harm to the devices attached at the feeding point. Sag can diminish the process performance and shorten the device's lifespan. Devices can be harmed by swell [6].
Among the most serious disruptions to susceptible loads are voltage sag and swells. The DVR has gained popularity as a low-cost option for protecting susceptible loads against voltage sag and swell. To mitigate

voltage sag and swell, DVR enters voltage in line and in synchronism with the grid supply voltage. Through an injecting transformer, the DVR is joined in series with the line. Figure 1 depicts a single-line model of a distribution network with a DVR that is linked to the feeders in series. When a load1 short-circuit happens, the voltage on the distributing bus drops. The voltage provided to the sensitivity load 2 sags as a result of this. A DVR is used to reestablish the voltage across this load. A DVR emits electricity to reestablish the load voltage to its basal values during a voltage dip or rise. The DVR swaps active and reactive power with the load throughout this procedure. Active power must be provided by the DVR in the event of voltage dips. The use of an energy storage device in the DVR is justified in this case. Batteries, capacitors, flywheels, and other energy storage systems are utilized in DVRs [7], [8]. The DVR may also reduce fault current via inserting lead voltage in quadrature with the fault current, thus raising the distributing feeder's actual fault impedance [9].

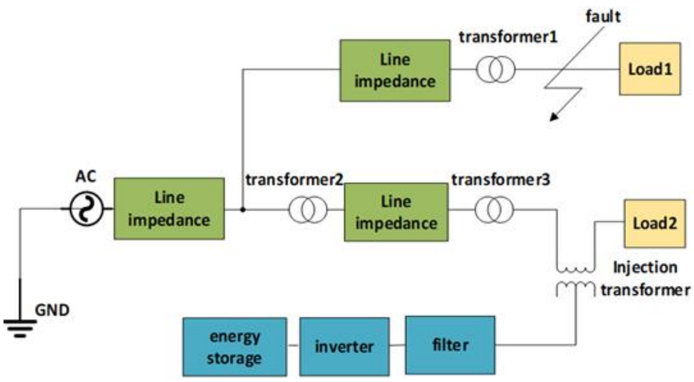


Figure 1. Single-line diagram of DVR connected in series with the feeder

The input voltage is linked in serial between the loads and the network and is controlled by the DVR. It's used to control the disruptions that might cause damage to important loads. Various kinds of DVR controls have been reported in various studies, including feed-forward and feedback, fuzzy and adaptive proportional-integral-fuzzy controllers [10]. The detection and determination of the reference voltage are the two key aspects of the DVR's control scheme. The first component of the DVR control scheme is the voltage sag detecting portion, which measures and analyzes grid voltage using a dip detection technique. The second section of the DVR control scheme is to calculate the reference voltage of the series inserted voltage. The technique for determining the series-inserted voltage reference signal is dependent on the kind of energy buffer, its capacity to sustain active power, and the sensitivity of the load to voltage perturbations [11]. The content of this paper is arranged as the structure of the DVR, The compensation strategies, control strategy of the DVR, practical swarm optimization, modeling and simulation, the total harmonics distortion of the load voltage and conclusion.

2. THE CONCEPTS OF THE DVR SYSTEM

The DVR is an energy storage device that is linked to the distribution network in series. The DVR's power circuit is made up of four major components (voltage source converter (VSC), series injection transformer, passive filter, and energy storage unit). Figure 1 shows the components of a device DVR.

2.1. Voltage source converter

The VSC transforms the DC voltage from the energy storage system into a three-phase AC voltage that may be controlled. A sinusoidal pulse width modulation technique is generally used to trigger the inverter gates. The injecting transformer is linked to the converter [12].

2.2. Injection transformer

The distributing feeders are linked in series with three single-phase transformers to link the voltage source inverter (VSI) (at the lowest voltage level) to the higher distribution voltage level. It connects the DVR device to the distribution grid through the HV-windings and converts and relates the voltage source converters' inserted compensatory voltages to the entering supply voltage. The three phase injection transformer can be wired with either (star/open star) or (delta/open star) windings [13].

2.3. Passive filters

The injection transformers' passive filters should be installed on either the high voltage or converting sides. The inverted pulse width modulation (PWM) waveform is converted into a sinusoidal waveform using filters in the DVR. This is accomplished by removing the undesirable harmonic components produced by the VSI. The adjusted output voltage is distorted by higher order harmonic components [14].

2.4. Energy storage device/control system

DVRs require actual power to compensate for voltage fluctuations in the distribution network. If a voltage disruption occurs, the DVR's real power should be provided by energy storage in this scenario. Energy storage options include lead-acid batteries, flywheels, and superconducting magnetic energy storage (SMES) [15].

3. THE COMPENSATING STRATEGIES

A variety of issues, like limited DVR power ratings, various load situations, and various forms of voltage dips, might restrict the ability to compensate for voltage dips. Certain loads are quite susceptible to phase angle jumps, whereas others are somewhat indifferent [16]. As a result, the control approach is determined by the characteristics of the load. There are three distinct DVR compensating voltage injection techniques. Figure 2 shows the phasor diagram of the compensation strategy.

3.1. Pre-sag compensation strategy

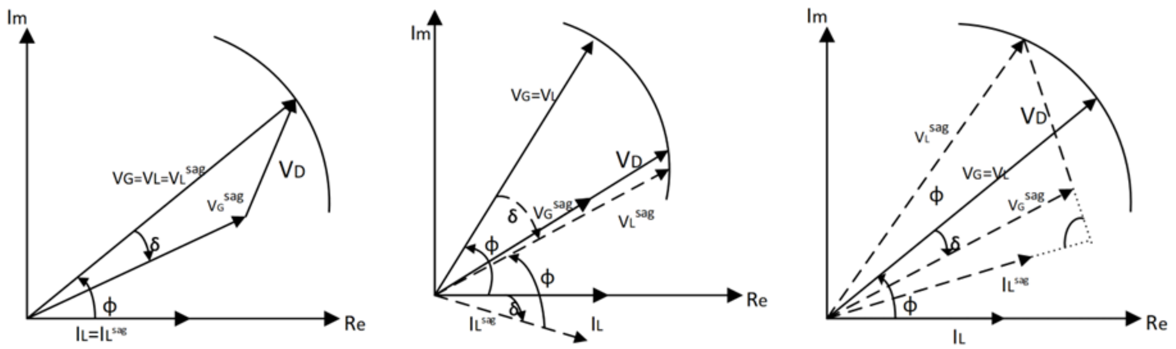
Figure 2(a) depicts the vector diagram of the pre-sag approach. The pre-sag compensation technique keeps the magnitude and phase angle of the load voltage static. This control strategy provides faultless performance from the load perspective. In three-phase systems, using this method outputs a balanced three-equitable voltage for the susceptible load [17], [18].

3.2. In-phase compensation strategy

Figure 2(b) depicts the vector diagram of the in-phase approach. The supplied voltage and the inserted voltage are in sync. The main gain of this technology is the small amplitude of the inserted voltage. When the magnitude of the supplied voltage is changed, the DVR creates the same voltage as the absent voltage [17], [18].

3.3. Minimum energy compensation strategy

The voltage vectors for the energy-optimized compensation are shown in Figure 2(c). The main idea behind such a technology is to utilise as much actual power from the grid as possible, hence lowering the amount of stored energy needed in the DC-link. As long as the voltage sag is relatively shallow, it is possible to correct for it by employing purely reactive power, hence the correction duration is not restricted [17], [18].



(a) (b) (c)

Figure 2. Vector diagram of DVR control techniques: (a) pre-sag compensation strategy, (b) in-phase compensation strategy, and (c) minimum energy compensation strategy

4. CONTROL STRATEGY OF DVR

The essential principles of a controller in a DVR are to discover voltage sag/swell happenings in the system, compute the adjusting voltage, generate trigger pulses for the Sinusoidal Pulse width modulation-based DC-AC converters, rectify any errors in the series voltage addition, and terminate the trigger pulses once the event happens. In the absence of voltage sags or swells, the controller can be utilized to move the DC-AC converter into rectifier mode to fill the capacitors in the DC energy connection. The DVR is controlled by the dqo conversion, also known as Park's transformation. The dqo technique calculates the sag deep and phase shift using begin and end timings. The instantaneous space vectors are used to describe the amounts. To begin with, change the voltage from abc to dqo. For the sake of ease, zero phase sequence parts are discarded. The feed forward dqo conversion for voltage sags/swells sensing is depicted in Figure 3 as a flow chart. Both of the three steps involve a detection procedure. The control is based on a voltage reference being compared to the recorded terminal voltage (Va, Vb, Vc). So, if supply voltage falls under 90% of the reference value, voltage sags are recognized, but voltage rises are identified when the supply voltage voltage rises to 25% of the reference value. The error signal is utilized as a modulated signal in order to generate a commutation pattern for the voltage source converter's power switches insulated gate bipolar transistors (IGBTs). The commutation patterns are created using the sinusoidal pulse width modulation technology (SPWM); the modulator controls the voltages. The PLL system generates a single sinusoidal signal that is in phase with the main voltage.

$$\begin{bmatrix} Vd \\ Vq \\ Vo \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & 1 \\ -\sin\theta & -\sin(\theta - 2\pi/3) & 1 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (1)$$

The equation describes the transition from a three-phase ABC system to a dqo stationary frame. The d-axis is in quadrature with the q-axis in this transformation, so phase A lines up with it. The theta (θ) is the angle formed between phase A and the d-axis [19]. A phase locked loop is a management technology that produces an output signal. The output signal's phase is proportional to the input signal's phase. It's used to make note of the arriving signal's phase. Phase-locked loop (PLL) is used for each source phase separately and is tailored to swiftly respond to supply phase changes. The size and phase of the pre-sag must be frozen in this procedure. The voltage generated by the PLL is phase-locked to the supply voltage. It requires a half-cycle delay. It's harder to execute in a real-time control scheme [20], [21].

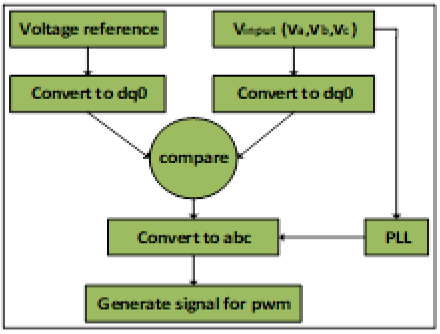


Figure 3. Flowchart of feed forward control technique for DVR based on dqo transformation

5. PI CONTROLLER

A PI controller processes such errors and sends the angle to the PWM signal generator. The drawback of a PI controller is its incapacity to respond to sudden changes in the error signal. The pulse signals to the IGBT gates of the voltage source converter are then generated by the PWM generator. Just during fault situations does a controller need to regulate or run the DVR [22], [23]. The elements of proportional integral (PI) controller are tuned by experiment and the hypothesis of true and false, therefore, the particle swarm optimization (PSO) method was used to identify the best controller settings.

6. PARTICLE SWARM OPTIMIZATION

PSO is a population-based modification approach used to solve nonlinear optimization issues. The swarming behavior of flying animals rushing and fishing for tutors propels PSO forward. When it comes to tackling optimization difficulties, this strategy excels. Each particle's velocity is dynamically adjusted based on its prior best experience and other nearby flying experiences. The velocity and position update equations are given by (2) and (3) as:

$$v_{i,j}^{(k+1)} = \&w * v_{i,j}^{(k)} + c_1 * r_1 * \left(p_{best\ i,j} - x_{i,j}^{(k)}\right) + c_2 * r_2 * \left(g_{best\,j} - x_{i,j}^{(k)}\right) \quad (2)$$

$$x_{i,j}^{(k+1)} = x_{i,j}^{(k)} + v_{i,j}^{(k+1)} \quad (3)$$

$i = 1,2, \dots \dots n, j = 1,2, \dots \dots m, k = 1,2, \dots \dots . t$
n is the number of particles in swarm, m is the search space's boundaries
t is the maximum number of repetitions
$v_{i,j}^{(k)}$ is the j^{h} element of the velocity of particle i at repetition k
w is the inertia weight factor, c_1, c_2 are the acceleration parameters
r_1 is the different numbers ranging from0 to1, r_2 is the different numbers ranging from 0 to 1
$pbest_{i,j}$ is the optimal location of
i^{th} particle at repetition k $gbest_j$ is the optimal location of the swarm until repetition k

In comparison to other random approaches, the PSO methodology will yield high-quality results in a shorter computation time and with a steadier convergence characteristic. Because PSO has storage, every particle in the swarm may remember its own and its neighbors' optimum positions in the search area, even if they have only been accessed once [24], [25].

7. MODELING AND SIMULATION

Figure 4 depicts the modeling and simulation of the electrical power system with DVR. This graph depicts the sag and swell generation that DVR compensates for. When a system malfunction occurs, the load is connected to the DVR through an injection transformer and, subsequently, to the bus. The value of KP=5, KI=100 for the trial-and-error method, while KP=49.9, KI=4560.7 for the PSO method.

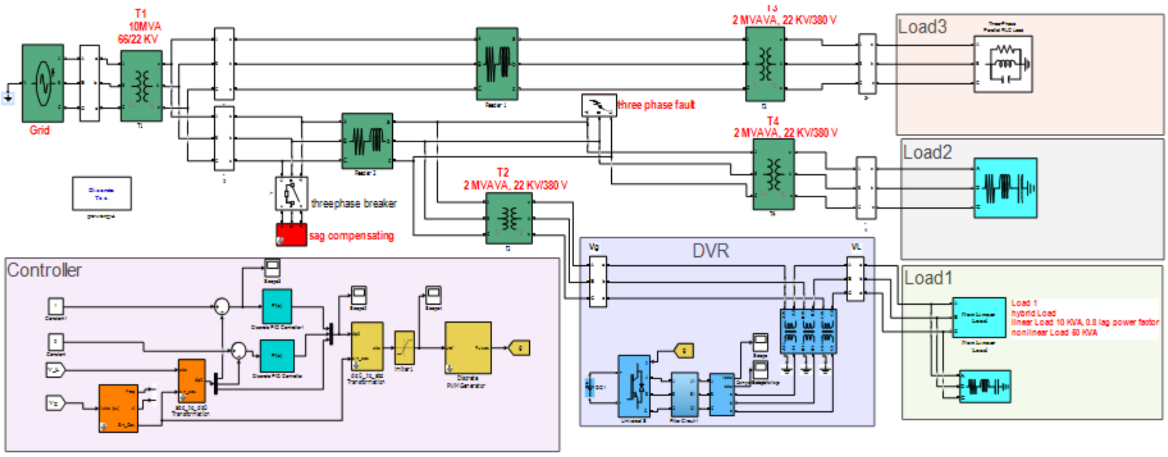


Figure 4. Modeling and simulation of the power system with DVR based on PI controlle

7.1. Voltage sag

According to Figure 5, which depicts the voltage inserted by the DVR and the associated load voltage with sag adjustment, from t=0.1 s to t=0.2 s, the grid voltage will be reduced by 65% of its normal value for 0.1 seconds. The load voltage is maintained at pre-sag voltage due to the DVR. The RMS shows the overshoot and undershoot of the voltage.

7.2. Voltage swell

Figure 6 depicts a simulation of a 40% three-phase voltage swell. It starts at 0.5 s and continues till 0.6 s. As may be visible from the results, the load voltage is saved at the nominal value with the aid of the DVR. The RMS shows the overshoot and undershoot of the voltage.

7.3. Voltage short interruption

Figure 7 shows a three-phase voltage interruption that starts at 0.3 s and lasts until 0.4 s. The load voltage is maintained at its nominal value with the help of the DVR. The RMS shows the overshoot and undershoot of the voltage. Figure 8 depicts the simulation of the electrical power system with DVR. This graph depicts the sag and swell generation that DVR compensates for. When a system malfunction occurs, the load is connected to the DVR through an injection transformer and subsequently to the bus.

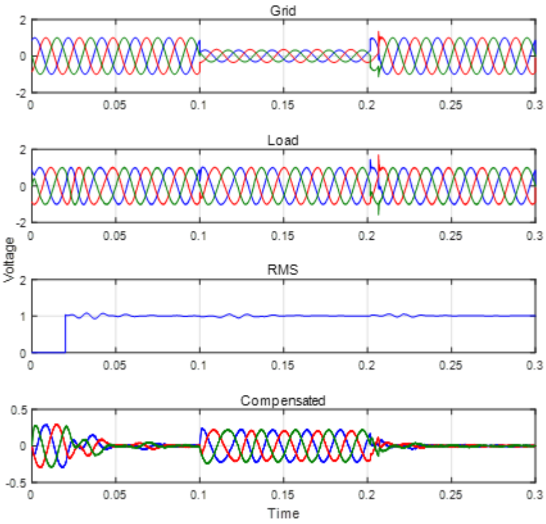


Figure 5. Three-phase sag voltage

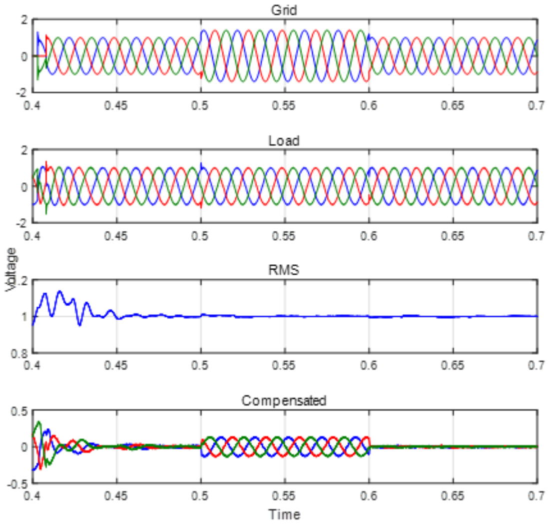


Figure 6. Three-phase swell voltage

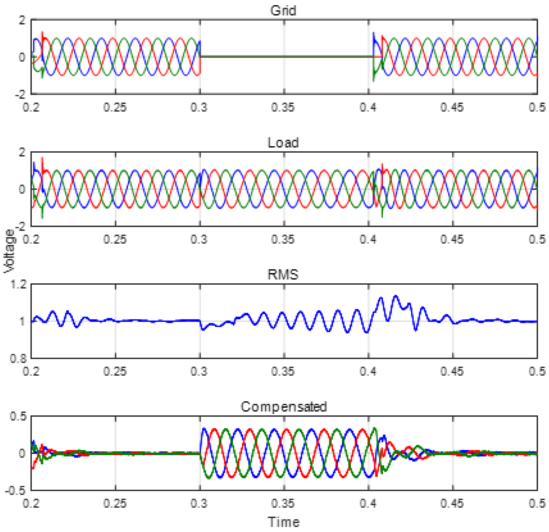


Figure 7. Three-phase interruption voltage

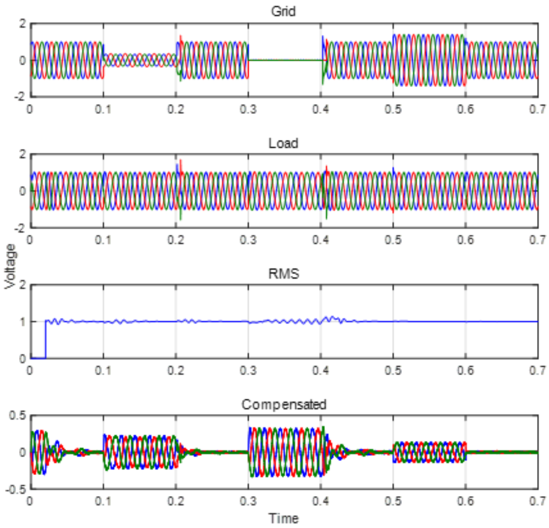


Figure 8. Three-phase sag, swell, and interrupt voltages

7.4. RMS voltage

Figure 9 shows the RMS of the load voltage with different disturbances, the value of overshoot, undershoot, steady state time, settling time, and integral absolute error (IAE) evaluated in Table 1 in the trial-and-error controller and Table 2 in the PSO controller. The settling time is evaluated at 2% of its normal value, from those values, there is an improvement in the work of the PSO over the work of the trial, and all the values of the PSO controller are less than their counterparts in the trial-and-error controller, which means that the error is less and less overshoot and undershoot, and the steady state time has improved.

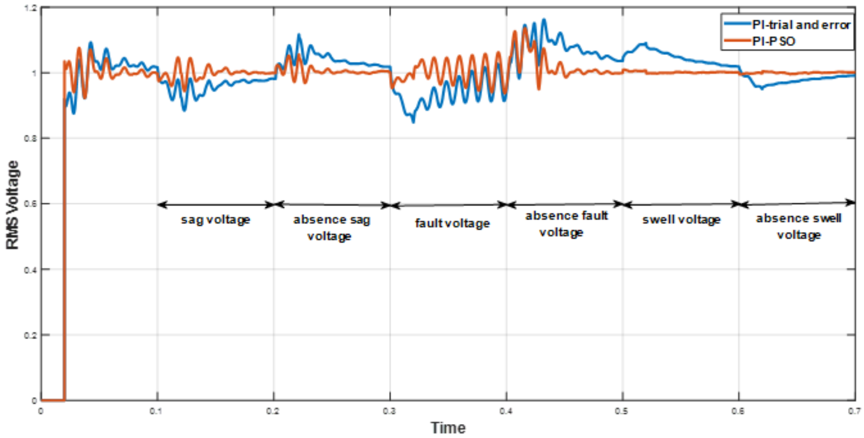


Figure 9. RMS of the load voltage

Table 1. PI-trial and error controller RMS voltage analysis

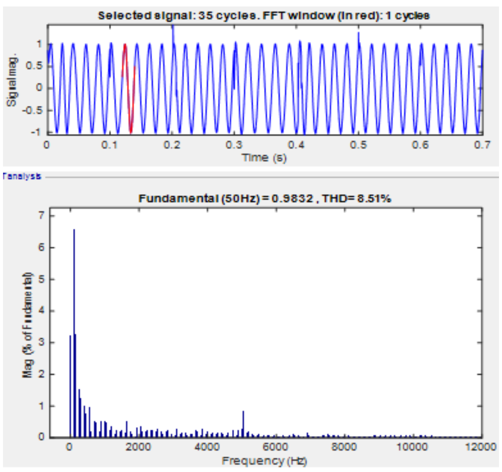
	sag	Absence sag	fault	Absence fault	swell	Absence swell
Overshoot	-	11%	-	16%	9%	-
Under shoot	12%	-	15%	-	-	5%
Steady state time	0.09	0.09	-	0.09	0.09	0.08
Settling time	0.09	0.09	0.05	0.09	0.09	0.06
IAE	0.0040	0.0039	0.0068	0.0073	0.0045	0.0026

Table 2. PI-PSO controller RMS voltage analysis

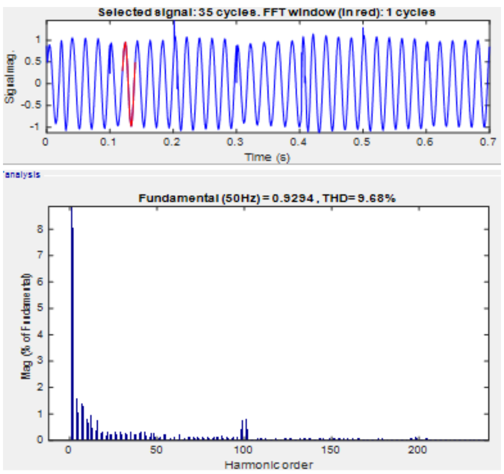
	sag	Absence sag	fault	Absence fault	swell	Absence swell
Overshoot	-	5%	-	13%	0.9%	-
Under shoot	6%	-	6%	-	-	0.4%
Steady state time	0.04	0.03	-	0.03	0.01	0.03
Settling time	0.03	0.02	0.04	0.02	-	-
IAE	0.0014	0.0015	0.0020	0.0025	0.0014	0.0014

8. THE TOTAL HARMONIC DISTORTION OF THE LOAD VOLTAGE

As demonstrated in Figure 10, the total harmonic distortion (THD) for the load voltage is evaluated by the simulation from fast Fourier transform (FFT). Figure 10(a) depicts the total harmonic distortion of the load voltage when the PSO controller is used, whereas Figure 10(b) depicts the total harmonic distortion of the load voltage when the trial-and-error controller is used. The value of THD is 8.51% for the PSO controller and 9.68% for the trial-and-error controller.



(a)



(b)

Figure 10. Frequency spectrum of load voltage for (a) PI-PSO controller and (b) PI-controller

9. CONCLUSION

In this paper, the different power problems are studied, such as sag voltage, swell voltage, and fault voltage, and using DVR. The PI controller for the DVR is used to solve the power problems. Two methods are used for tuning the parameters of the PI controller: trial and error and the intelligent optimal method. The utilized optimal method is the PSO method. The value of THD changed from 9.68% in the case of the trial and error to 8.51% in the case of PSO. The work of the PSO has improved over the trial. The values of the PSO controller are less than their counterparts in the trial-and-error controller, which means that the error is less and less overshoot and undershoot, and the steady state time has improved.

REFERENCES

[1] E. Babaei, M. F. Kangarlu, and M. Sabahi, "Mitigation of voltage disturbances using dynamic voltage testorer based on direct converters," *IEEE Transactions on Power Delivery*, vol. 25, no. 4, pp. 2676–2683, Oct. 2010, doi: 10.1109/TPWRD.2010.2054116.

[2] A. I. Omar, S. H. E. Abdel Aleem, E. E. A. El-Zahab, M. Algablawy, and Z. M. Ali, "An improved approach for robust control of dynamic voltage restorer and power quality enhancement using grasshopper optimization algorithm," *ISA Transactions*, vol. 95, pp. 110–129, Dec. 2019, doi: 10.1016/j.isatra.2019.05.001.

[3] S. A. Rahman and E. Dagnew, "Voltage sag compensation using direct converter based DVR by modulating the error signal," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 2, p. 608, Aug. 2020, doi: 10.11591/ijeecs.v19.i2.pp608-616.

[4] A. B. Mohammed, M. A. Mohd Ariff, and S. Najwa Ramli, "Power quality improvement using dynamic voltage restorer in electrical distribution system: an overview," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 1, p. 86, Jan. 2020, doi: 10.11591/ijeecs.v17.i1.pp86-93.

[5] J. A.-K. Mohammed, A. A. Hussein, and S. R. Al-Sakini, "Voltage disturbance mitigation in Iraq's low voltage distribution system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 1, p. 47, Jan. 2020, doi: 10.11591/ijeecs.v17.i1.pp47-60.

[6] C. S. P and S. C R, "Synthesis of model predictive controller for an identified model of MIMO process," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 2, p. 941, Feb. 2020, doi: 10.11591/ijeecs.v17.i2.pp941-949.

[7] A. Meena, S. Islam, S. Anand, Y. Sonawane, and S. Tungare, "Design and control of single-phase dynamic voltage restorer," *Sādhanā*, vol. 42, no. 8, pp. 1363–1375, Aug. 2017, doi: 10.1007/s12046-017-0653-5.

[8] Y. M. Esmail, A. H. K. Alaboudy, M. S. Hassan, and G. M. Dousoky, "Mitigating power quality disturbances in smart grid using FACTS," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 3, p. 1223, Jun. 2021, doi: 10.11591/ijeecs.v22.i3.pp1223-1235.

[9] D. V. Chinmay and D. V. Chaitanya, "Optimum design of dynamic voltage restorer for voltage sag mitigation in distribution network," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 3, p. 1364, Sep. 2019, doi: 10.11591/ijpeds.v10.i3.pp1364-1372.

[10] A. B. Mohammed, M. A. M. Ariff, and S. N. Ramli, "An improved method for efficient controlling of the dynamic voltage restorer to enhance the power quality in the distribution system," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 4, p. 1958, Dec. 2020, doi: 10.11591/ijpeds.v11.i4.pp1958-1965.

[11] A. K. Sadigh and K. M. Smedley, "Review of voltage compensation methods in dynamic voltage restorer (DVR)," in *2012 IEEE Power and Energy Society General Meeting*, Jul. 2012, pp. 1–8, doi: 10.1109/PESGM.2012.6345153.

[12] M. A. A. M. A. Aziz, "Modeling and simulation of dynamic voltage restore in power system," M.S. thesis, Electerical Power And Machines Department, Azhar University, Cairo, Egypt, 2012.

[13] D. Francis and T. Thomas, "Mitigation of voltage sag and swell using dynamic voltage restorer," in *2014 Annual International Conference on Emerging Research Areas: Magnetics, Machines and Drives (AICERA/iCMMD)*, Jul. 2014, no. 4, pp. 1–6, doi: 10.1109/AICERA.2014.6908218.

[14] N. Abas, S. Dilshad, A. Khalid, M. S. Saleem, and N. Khan, "Power quality improvement using dynamic voltage restorer," *IEEE Access*, vol. 8, pp. 164325–164339, 2020, doi: 10.1109/ACCESS.2020.3022477.

[15] S. Jain, S. S. Thakur, and S. P. Phulambrikar, "Fuzzy controller based DVR to mitigate power quaity and reduce the harmonics distortion of sensitive load," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 1, no. 5, pp. 351–361, 2012.

[16] C. Benachaiba and B. Ferdi, "Power quality improvement using DVR," *American Journal of Applied Sciences*, vol. 6, no. 3, pp. 396–400, Mar. 2009, doi: 10.3844/ajas.2009.396.400.

[17] J. G. Nielsen, M. Newman, H. Nielsen, and F. Blaabjerg, "Control and testing of a dynamic voltage restorer (DVR) at medium oltage level," *IEEE Transactions on Power Electronics*, vol. 19, no. 3, pp. 806–813, May 2004, doi: 10.1109/TPEL.2004.826504.

[18] H. Chen, Y. Shao, and S. Hu, "Design of dynamic voltage restorer," *OALib*, vol. 07, no. 07, pp. 1–7, 2020, doi: 10.4236/oalib.1106582.

[19] sanjay haribhai Chaudary and Mr. Gaurav gangil, "Mitigation of Voltage sag/swell using Dynamic Voltage Restorer (DVR)," *IOSR Journal of Electrical and Electronics Engineering*, vol. 8, no. 4, pp. 21–38, 2013.

[20] R. Pal and S. Gupta, "State of the art: dynamic voltage restorer for power quality improvement," *Electrical & Computer Engineering: An International Journal*, vol. 4, no. 2, pp. 79–98, Jun. 2015, doi: 10.14810/ecij.2015.4208.

[21] D. D, S. Bugata, and K. J, "A control strategy on power quality improvement in consumer side using custom power device," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 15, no. 1, p. 80, Jul. 2019, doi: 10.11591/ijeecs.v15.i1.pp80-87.

[22] K. Sandhya, A. J. Laxmi, and M. P. Soni, "Design of PI and fuzzy controllers for dynamic voltage restorer (DVR)," *AASRI Procedia*, vol. 2, pp. 149–155, 2012, doi: 10.1016/j.aasri.2012.09.027.

[23] C. K. Sundarabalan and K. Selvi, "Power quality enhancement in power distribution system using artificial intelligence based dynamic voltage restorer," *International Journal on Electrical Engineering and Informatics*, vol. 5, no. 4, pp. 433–446, Dec. 2013, doi: 10.15676/ijeei.2013.5.4.4.

[24] K. Jeyaraj, D. Durairaj, and A. I. S. Velusamy, “Development and performance analysis of PSO-optimized sliding mode controller–based dynamic voltage restorer for power quality enhancement,” *International Transactions on Electrical Energy Systems*, vol. 30, no. 3, pp. 1–14, Mar. 2020, doi: 10.1002/2050-7038.12243.
[25] N. Kassarwani, J. Ohri, and A. Singh, “Performance analysis of dynamic voltage restorer using improved PSO technique,” *International Journal of Electronics*, vol. 106, no. 2, pp. 212–236, 2019, doi: 10.1080/00207217.2018.1519859.

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