Biogeography Based Optimization for Enhancing Dynamic Performance of Dynamic Voltage Restorer in Mitigating Power Quality Problems

S. Asha Kiranmai[1,2](✉) and A. Jaya Laxmi[3]

[1] Electrical Engineering, Osmania University College of Engineering, Hyderabad, India
asha_ks2006@yahoo.co.in

[2] Electrical and Electronics Engineering, Bhoj Reddy Engineering College for Women, Hyderabad, India

[3] Electrical and Electronics Engineering and Principal, JNTUH University College of Engineering, Science and Technology, Hyderabad, India

Abstract. The concern for good power quality is increasing day by day due to great damage caused by power quality problems in terms of scrambling of data, malfunctioning and failure of equipment of public or industrial facilities. To reduce these effects, there is a requirement to improve the quality of power, by using fast acting custom power devices with enhanced dynamic performance in the distribution system. This paper mainly concentrates on the mitigation of frequently occurring power quality problems of voltage sag, voltage swell, voltage unbalance as well as interruption. For this, one of the custom power devices, Dynamic Voltage Restorer is used. Biogeography Based Optimization based PI controllers are implemented for the device to improve its dynamic response making it faster with less transients in mitigating the problems. MATLAB simulations are carried out for conditions of voltage sag, voltage swell, voltage unbalance as well as interruption and load voltage dynamics with Dynamic Voltage Restorer using Biogeography Based Optimization based PI controllers are compared with conventional PI controllers and found better results in terms of minimum, maximum peak voltages as well as settling time.

Keywords: Biogeography Based Optimization · Dynamic Voltage Restorer · Dynamic performance · Mitigation · PI controller gains · Power quality problems

1 Introduction

Nowadays, electricity consumers not only require reliability of the power supply, but also need quality power. With the use of electronic, power electronic and microelectronic devices in many equipment like computers, programmable logic controllers and motor drivers, the power quality is deteriorated [1]. From past several years, the demand for clean power is increasing as high level of power quality is required to ensure the proper,

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continuous, safe and reliable operation of the sensitive equipment. The impacts of poor power quality have led to the focus on detection [2–4] and mitigation of them. To reduce the effects of problems of power quality, mostly custom power devices are used in the distribution system, as they are fast and efficient in mitigating the problems.

Dynamic Voltage Restorer (DVR) belongs to the category of custom power devices. It is one of the most effective and efficient modern power electronic devices used in power distribution systems for the mitigation of power quality problems. DVR is a series connected static device consisting of voltage source inverter which injects voltage into the line in series with it, by using a series transformer and maintains voltage of the load to be at rated value of voltage, irrespective of the variations in source voltages due to power quality problems. For the improvement of quality of power, i.e., mitigation of voltage sag, voltage swell, voltage unbalance and interruption, DVR is used [5–10]. PI controllers are usually used for voltage source inverter controlling in the DVR, as they can easily be implemented and have robust performance when operating in varied conditions.

To get the desired control response, the gain of the PI controller should be tuned properly. Unfortunately, tuning of PI controller's gains is hard in practice due to high order and time delay systems. Here comes the need for optimization algorithms to obtain the optimum values of the gains for the controller. In [11], an optimization method based upon biogeography was proposed by D. Simon. The Biogeography Based Optimization (BBO) algorithm was developed by him which focuses on the mechanisms of mutation and migration. The mathematical models are the species in biogeography. The models indicate species migration from one to other region, how species appear as well as extinct. Performance of Biogeography Based Optimization was compared with other techniques of optimization like Evolutionary Strategy, Ant Colony Optimization, Genetic Algorithms, Particle Swarm Optimization, etc. and promising results were obtained using BBO technique. Later on, successful implementation of BBO technique is done in different areas like robot controller tuning [12], harmonics minimization in asymmetric multilevel inverter [13], voltage profile improvement of distribution network by using Distributed Static Compensator [14], optimal design of IIR low-pass filter [15], multi-machine power system stabilizer [16], economic load dispatch [17], optimal design of a synchronous reluctance motor [18], control of autonomous vehicles [19] and harmonics reduction in Hybrid Renewable Energy Sources [20].

This paper aims at the optimization of the gains of PI controllers of the DVR using BBO technique. Performance of DVR with BBO based PI controllers is analyzed for the conditions of voltage sag, voltage swell, voltage unbalance as well as interruption and the results are compared with conventional PI controllers. The paper consists of 4 sections: Sect. 2 describes about the BBO algorithm in detail along with its implementation for DVR. Section 3 shows the MATLAB simulation model and the control circuit of the DVR system used for the mitigation of voltage sag, voltage swell, voltage unbalance and interruption problems. The test results and discussions are given in this section. Section 4 gives the conclusions of the work.

2 Biogeography Based Optimization and Its Implementation

BBO is one of the evolutionary algorithms depending on biogeography. This algorithm focuses on geographical distribution of the living organisms. It mainly explains how the number of species increase or become extinct. The Habitat Suitability Index (HSI) for the geographical regions defines a suitable place for the species to reside. HSI is based on rainfall, vegetation, local temperature and land area of that region. The regions having high HSI are suitable for the biological species to live. The features identified in the habitats are called Suitability-Index-Variables (SIVs). For higher value of HSI habitat, species immigration of lower rate and higher rate for species emigration will be there, as it already has full population. For lower HSI habitat, species immigration of higher rate and low rate of species emigration will be there [11].

The BBO algorithm is utilized to obtain the optimum values of PI controllers' gains (K_{p1}, K_{i1}, K_{p2}, K_{i2}) used for controlling switching pulses for voltage source inverter in DVR to get better output performance. The sum of Integral of Time weighted Squared Errors (ITSEs) indicated in Eq. (1) is the chosen objective function. This objective function based on ITSE is selected in order to decrease the overshoots and settling time. 'e_1' and 'e_2' are the input errors of the two PI controllers.

$$\mathrm{ITSE}_1 + \mathrm{ITSE}_2 = \int_0^t te_1^2(t)dt + \int_0^t te_2^2(t)dt \tag{1}$$

The steps in BBO algorithm are as follows:

1. Initialization of BBO parameters: probability of mutation = 0.01, maximum immigration and emigration rates = 1, habitat modification probability = 1, numerical integration step size = 1, population size = 10, number of iterations = 50, elitism parameter = 2, number of SIVs = number of parameters of the controller. The values are chosen based on several simulations to get accurate results with less computation time.
2. Within the provided defined range, the SIVs of each habitat are chosen at random. Each habitat is a potential solution to the given problem.
3. Fitness value is evaluated, i.e., HSI value is computed for all the habitats in the population set for the specified emigration rate, rate of immigration and number of species.
4. The HSI value is used to identify elite habitats.
5. Perform migration operations on every non-elite habitat in a probabilistic manner. Each solution set is then updated. The HSI of each set is computed after each alteration.
6. Update the habitat probability count for each species. Perform the mutation process on the non-elite habitat and determine the value of HSI for every new habitat.
7. Go to step 3 for the next iteration, or halt iterations once a specified number of iterations have been completed.

3 Simulation Model and Results

A MATLAB simulation model shown in Fig. 1 is used to simulate DVR system with conventional and BBO based PI controllers, which is used for the mitigation of the voltage sag, voltage swell, voltage unbalance and interruption. Circuit has distribution substation of 33/11 kV rating which is linked to distribution line of 2 km, consisting of distribution transformer of 11/0.433 kV which is giving power to 190 kW, 140 kVAr load [20]. Balanced LLLG fault with some fault impedance is used to create voltage sag. Voltage swell is created by switching on the 3-phase capacitor to the line. Voltage unbalance is created by a 3-phase unbalance fault. The interruption is introduced by opening circuit breaker 1 (CB 1), thereby disconnecting the supply to the line.

The control circuitry used for the generation of gate triggering pulses to the voltage source inverter is shown in Fig. 2. The source side 3-phase instantaneous per unit voltages 'V_{sabc}' are converted into d and q components of rotating reference frame. Comparison of these values is done with reference values of 1 p.u. and 0 p.u. respectively. Errors obtained are processed through PI controllers and generated signals are again converted to abc components. These signals are compared with the carrier triangular waveform of 2.5 kHz using sinusoidal-pulse-width-modulation technique and pulses generated are given to the inverter of DVR. Based upon these pulses to the gate, the voltage source inverter injects series voltage into the line thus compensating voltage sag, voltage swell, voltage unbalance and interruption conditions.

The circuit in Fig. 1 is simulated for different power quality problems of voltage sag of 0.7 p.u., voltage swell of 1.3 p.u., voltage unbalance of 12.5% PVUR with 3-phase voltages of 0.8 p.u., 0.7 p.u., 0.9 p.u. and interruption. The corresponding 3-phase load voltages without DVR, using conventional PI controller based DVR and BBO-PI controller based DVR are indicated from Fig. 3 to Fig. 14. The PI controllers' gains of Conventional PI and BBO-PI are given at Table 1. From the figures, it's seen that during disturbances, the load voltages deviate from 1 p.u. without DVR. With DVR, the load voltages retained to 1 p.u. during disturbances with some transients at the beginning and ending of the period. It is also observed that using BBO-PI based DVR, the load voltages

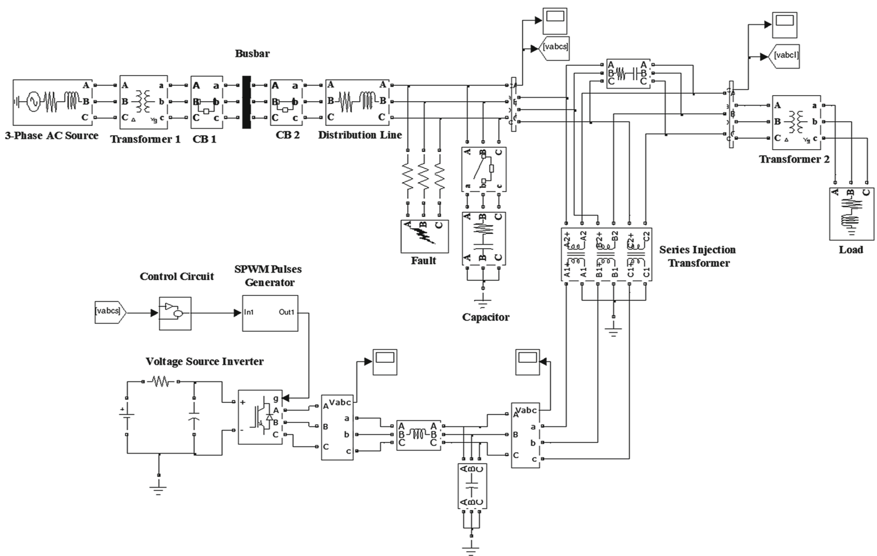

Fig. 1. Simulation circuit diagram of the system

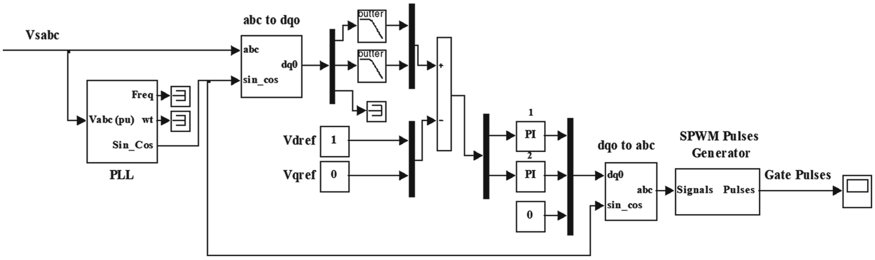

Fig. 2. Control circuit for generating gate pulses to the inverter

Table 1. PI Controllers' Gains for Conventional PI and BBO-PI based DVR

PI Controllers' Gains	K_{p1}	K_{i1}	K_{p2}	K_{i2}
Conventional PI Controllers	0.95	0.5	0.95	0.5
BBO-PI Controllers	1.2024	0.1901	1.0303	0.2076

have retained at 1 p.u. during the disturbance period with less transients and overshoots when compared to the use of conventional PI controllers.

From all the results obtained, it's clear that the DVR is able to compensate for voltage sag, voltage swell, voltage unbalance and interruption problems effectively. The

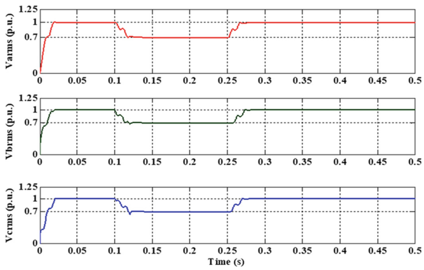

Fig. 3. 3-Phase load voltages during sag without DVR

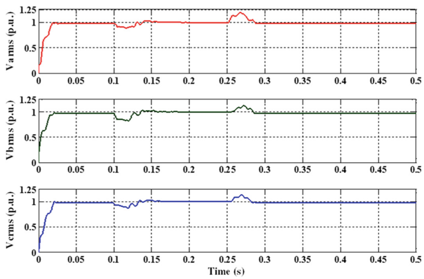

Fig. 4. 3-Phase load voltages during sag with conventional PI controller based DVR

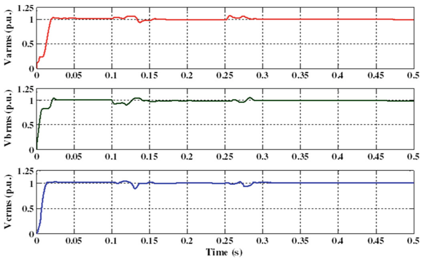

Fig. 5. 3-Phase load voltages during sag with BBO-PI controller based DVR

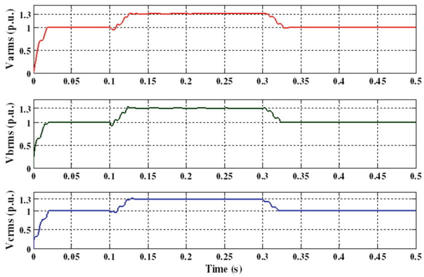

Fig. 6. 3-Phase load voltages during swell without DVR

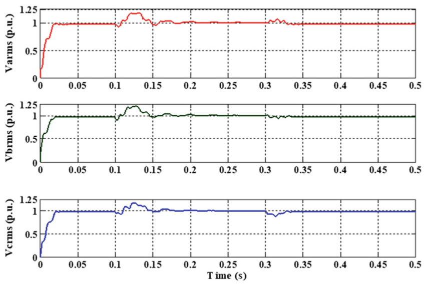

Fig. 7. 3-Phase load voltages during swell with conventional PI controller based DVR.

Minimum voltage peak, maximum voltage peak and settling time in case of conventional and BBO PI controllers in DVR for the conditions of voltage sag, voltage swell, voltage unbalance as well as interruption, are indicated in Table 2. From the table, it can be clearly seen that dynamics of DVR with BBO based PI controller is better than with conventional PI controller.

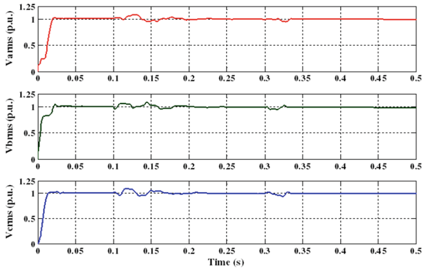

Fig. 8. 3-Phase load voltages during swell with BBO-PI controller based DVR

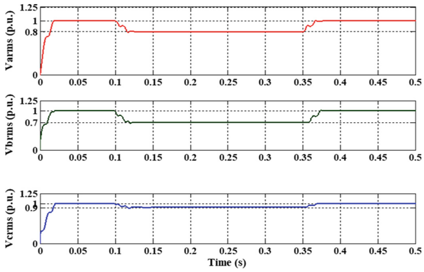

Fig. 9. 3-Phase load voltages during unbalance without DVR

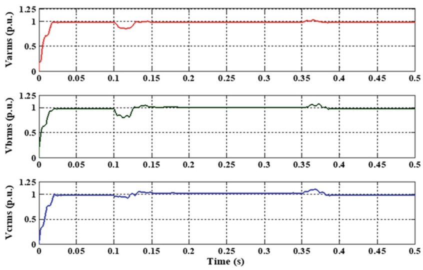

Fig. 10. 3-Phase load voltages during unbalance with conventional PI controller based DVR

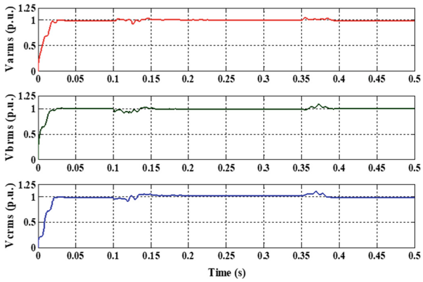

Fig. 11. 3-Phase load voltages during unbalance with BBO-PI controller based DVR

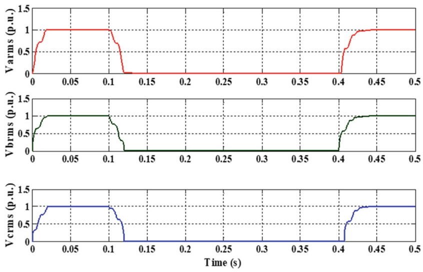

Fig. 12. 3-Phase load voltages during interruption without DVR

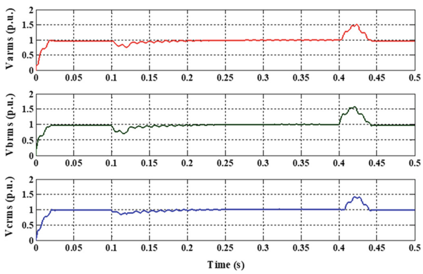

Fig. 13. 3-Phase load voltages during interruption with conventional PI controller based DVR

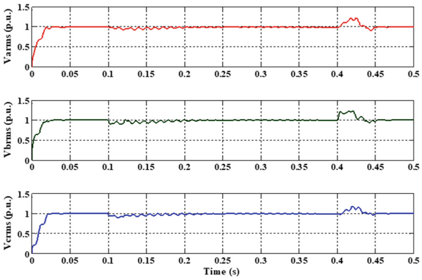

Fig. 14. 3-Phase load voltages during interruption with BBO-PI controller based DVR

Table 2. Comparison of Dynamic Performance of PI and BBO-PI based DVR

Power Quality Problems	With Conventional PI Controllers			With BBO based PI Controllers		
	Minimum Peak Voltage	Maximum Peak Voltage	Settling Time	Minimum Peak Voltage	Maximum Peak Voltage	Settling Time
Voltage Sag	0.812 p.u.	1.188 p.u.	0.0337 s	0.902 p.u.	1.077 p.u.	0.0236 s
Voltage Swell	0.880 p.u.	1.205 p.u.	0.0590 s	0.940 p.u.	1.096 p.u.	0.0437 s
Voltage Unbalance	0.793 p.u.	1.096 p.u.	0.0273 s	0.917 p.u.	1.082 p.u.	0.0177 s
Interruption	0.706 p.u.	1.596 p.u.	0.0815 s	0.901 p.u.	1.220 p.u.	0.0614 s

4 Conclusion

In this paper, BBO is implemented for DVR in mitigation of voltage sag, voltage swell, voltage unbalance and interruption problems. It is observed through MATLAB simulations that DVR with BBO based PI controllers gives better dynamic performance than conventional PI controllers. The minimum peak voltage, maximum peak voltage and the settling time of the load voltage during power quality problems is less when BBO is used. Thus, BBO based DVR can be effectively used for the mitigation of voltage sag, voltage swell, voltage unbalance as well as interruption, occurring in the distribution system for faster and reliable operation. It can easily be implemented practically using Field Programmable Gate Array.

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