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Optimized FOPID controller for power quality enhancement between feeders using interline dynamic voltage restorer

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ABSTRACT

This paper proposes a novel control scheme for Interline dynamic voltage restorer (IDVR). The optimized fractional order PID (FOPID) controller is used in this work for power quality enhancement such as voltage regulation, harmonics distortion reduction, voltage sag and swells compensation, fault compensation etc. The gain parameters of FOPID controller are tuned by gravitational search algorithm (GSA). The performance of the suggested controller is evaluated by contrasting it with other optimization technique such as particle swarm optimization and cuckoo-search optimization algorithm. These simulation results represents that FOPID with GSA works better than the other techniques in terms of power quality enhancement.

Selection and peer-review under responsibility of the scientific committee of the Emerging Trends in Materials Science, Technology and Engineering.

1. Introduction

Nowadays PQ problems are raised due to the increase in non-linear loads such as induction motor, inverter etc. In order to maintain the supply of quality power, a balanced sinusoidal voltage is needed [1]. This is achieved by compensators. Conventionally, the compensation is carried out by using bulk capacitors. But the design of capacitor values required for compensation is a critical issue when using bulk capacitor. Hence power conditioners such as STATCOM, DVR, UPFC, UPQC etc., are used [2]. A DVR compensate voltage distortion in feeder by injecting series with the voltage feeded. This is series compensation. DVR may be placed in adjacent feeders with common DC bus [3]. This is called as Interline Dynamic voltage restorer (IDVR). It controls the power flow for the entire line. IDVR comprises of two DVRs. Each DVR is connected to the separate power line through common DC link. The main objective of IDVR is reactive and real power compensation thereby mitigates voltage sag [4]. The DVR may be a current source converter (CSI) or voltage source converter (VSI). The VSI or CSI is controlled by controllers. Many literatures reports proportional integral (PI) controller as the control system for compensating voltage [5–7]. The PI controller compares the actual load voltage with the reference voltage. The PI controller generates the required modulation index (MI) depends on error between actual and desired load voltage. This MI is then compared with PWM generation. The PWM generator produces the gate pulses as required by VSI or CSI. The inverter injects the compensation voltage from the transformer and filter. The filter is to mitigate the harmonics. The main limitations of PI controller are the tuning of gain values and design. The standard PID controller is improved to a form based on fractional order calculus called FOPID controller [8]. The FOPID controller outperforms conventional PID controller in terms of control performance. This improvement in performance is due to the introduction of fractional order term λ and μ [9]. Eventhough the FOPID controller has many advantages over conventional PID controller, the extra terms in FOPID controller makes the tuning process more difficult. The tuning of FOPID parameters is very important since it decides the steady state and transient performance, stability and robustness. To alleviate the issue of tuning FOPID controller, many researchers proposed analytical methods and optimization methods [10]. In conventional analytical methods, the process of tuning is complex for large system. Hence evolutionary based optimization algorithms like Genetic algorithm (GA), Differential Evolution (DE), Particle Swarm Optimization (PSO) algorithm, Ant colony optimization algorithm (ACO) etc. are used [11–13] Fig. 1

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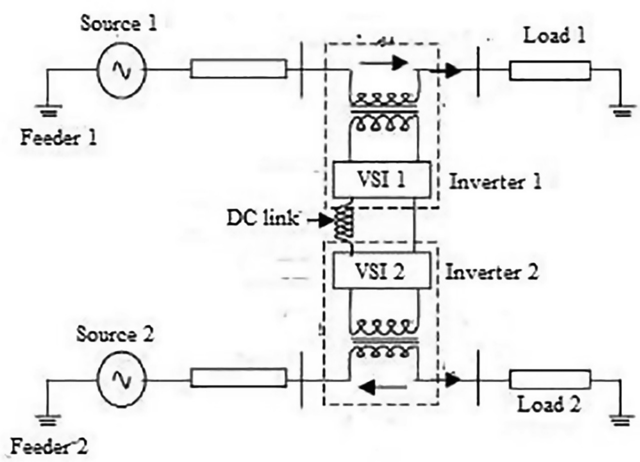

Fig. 1. Schematic diagram.

In this work, the FOPID controller is used for real and reactive power compensation using IDVR. The gravitational search algorithm is used as an optimization algorithm for tuning the FOPID controller.

2. Methodology

2.1. Idvr

IDVR is connected in series with the lines. It comprises of two DVRs connected through common DC link voltage. The voltage sag is mitigated in distribution line by real and reactive power compensation. Of two DVR, one DVR mitigates the voltage sag in the line from the DC link voltage, while other DVR stock up the consumed energy through second distribution line. Hence voltage sags of high value also able to compensate by IDVR. The schema of IDVR is shown in Figure. These IDVR consists of two DVRs that are connected to two feeders of different rating. Of the two DVR, one DVR responsible for mitigating voltage sag and the other DVR compensates the DC link voltage reduced due to real power compensation taking for mitigating voltage sag. Voltage sag is more prominent in transmission system than in the distribution system. In this proposed work, it is believed that the feeder 1 have more impact of voltage sag than feeder 2. Hence DVR1 operates for voltage sag compensation and DVR2 compensates for real power compensation.

2.2. FOPID controller

Fractional order controllers are working based on the fractional calculus. The Conventional PID controller based on fraction calculus is called FOPID controller. The integral and derivatives in PID controller may be any real number in fractional calculus. The FOPID controller is designated as $PI^{\lambda}D^{\mu}$. The function is defined as,

$$u(t) = K_p e(t) + K_i \left(\frac{de(t)}{dt}\right)^{\frac{1}{\lambda}} + K_d \left(\frac{de(t)}{dt}\right)^{\mu} \quad (1)$$

In FOPID controller, there is five degree of freedom i.e five parameters such as $(K_p, K_i, K_d, \lambda, \mu)$ needs to be designed inorder to obtain reliable controller function. In those parameters, λ *and* $\mu$is not an integer. Hence proper selection of those parameters is critic in controller design. In this work, the FOPID controller parameters are optimized by using GSA.

2.3. Gravitational search algorithm (GSA)

GSA is algorithm for meta heiuristic optimization based on the Newtonian law of gravitation. The particles are the objects having different masses [14]. Each particle having different masses. The particle with heaviest mass is considered as an optimal solution. The force of attraction between particles is directly proportional to masses of the particles and inversely proportional to square of the distance between them. The parameters in this algorithm are position of the article, mass of inertia and the gravitational mass. The heaviest mass particle moves slowly than lighter one. The velocity of the particle is calculated by using inertial and gravitational mass. The velocity is updated using fitness function. The algorithm reaches an optimal solution by adjusting the gravitational and inertial mass. The heaviest mass particle which is the optimal solution attracted all other lighter particles in search space. These algorithm for the GSA algorithm is shown below:

3. Algorithm

3.1. Step 1

Initialization of particles i.e. masses
The position is randomly assigned as follows

$$X_n = x_n^1, x_n^2, \ldots\ldots x_n^d$$

where n = 1,2,3. . ...N_p
$X_n^d$is the n^{th} particle position in d dimensional space
N_p is the Total number of particles
Step 2
Calculate the fitness function for all particles and also found the best and worst solution.

The function used in this work is minimization of error in FOPID controller. Therefore the fitness function is Integral square error (ISE). The fitness function is minimization function.

$$F = \int (e(t))^2 dt \quad (2)$$

F is the Fitness function ISE.
best (iter) = min*(F)*, best F
worst (iter) = max*(F)* , worst F
Step 3:
Calculation of gravitational constant *G(iter)*

$$G(iter) = G_0 \exp\left(-\alpha \frac{iter}{iter_{max}}\right) \quad (3)$$

where G0=100 and α=20
Step 4:
Calculation of mass of particles

$$S_i(iter) = \frac{F_i(iter) - worst(iter)}{best(iter) - worst(iter)} \quad (4)$$

$$Mass(iter) = \frac{S_i(iter)}{\sum_{j=1}^{N} S_j(iter)} \quad (5)$$

Step 5:
Calculate acceleration of particles based on law of gravity and Newton second law of motion

$$acc(iter) = \sum_{j \in nbest} rand_j G(iter) \frac{Mass_j(iter)}{R_{ij}(iter) + \varepsilon} (x_j - x_i) \quad (6)$$

j=1,2,. . ...Np

$$R_{ij} = \| X_i(iter), X_j(iter) \|$$

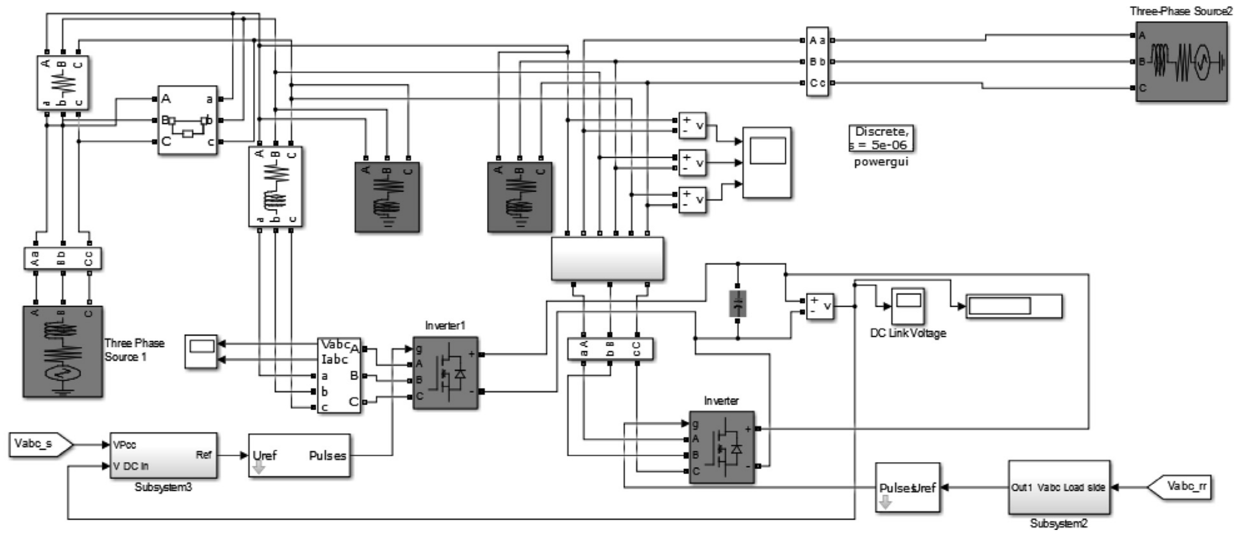

Fig. 2. Simulation diagram.

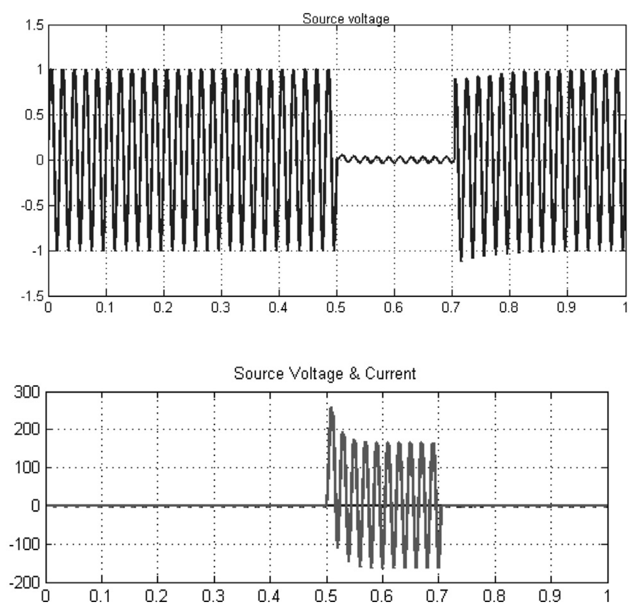

Fig. 3. Source voltage and Source current with sag.

where,
acc is acceleration
randj is random variable [0,1]
εis the constant
Rij is the Euclidean distance
nbest is the first n number of particles with best fitness
nbest varies from n0 to 1

Table 1
Simulation Parameters.

Parameter	Feeder 1	Feeder 2
Source Voltage	415 V	415 V
Load resistance	50 Ω	50 Ω
Load inductance	100 mH	100 mH
Filter resistance	0.5 Ω	0.5 Ω
Filter inductance	1 mH	1 mH
DC link capacitance	4700 μF	4700 μF
DC link voltage	1200 V	1200 V

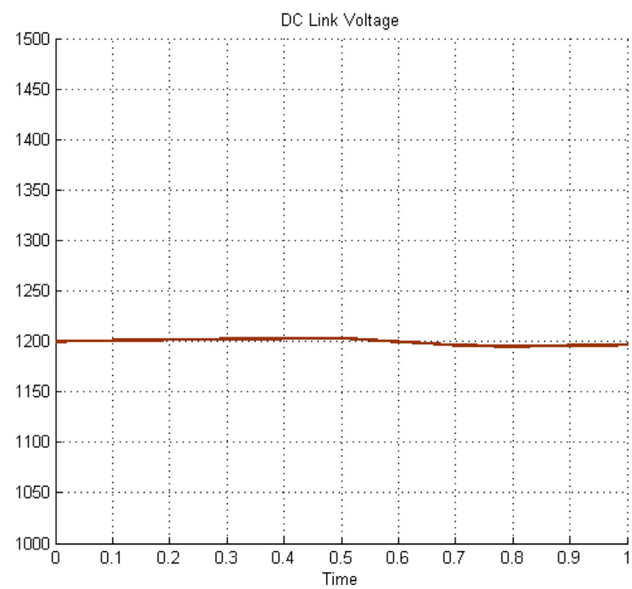

Fig. 4. DC link voltage.

n0 is the initial value
Step 6:

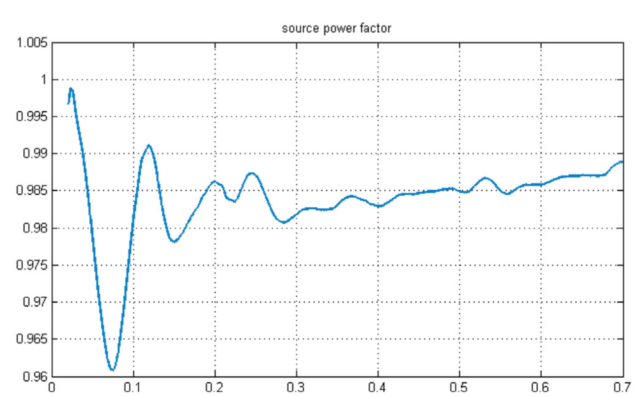

Fig. 5. Power Factor.

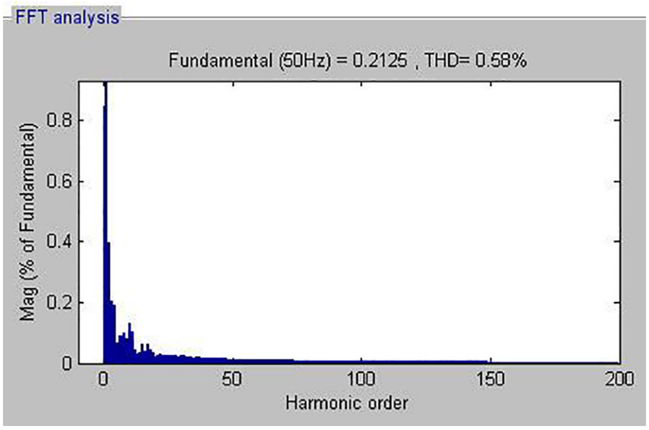

Fig. 6. THD of source current.

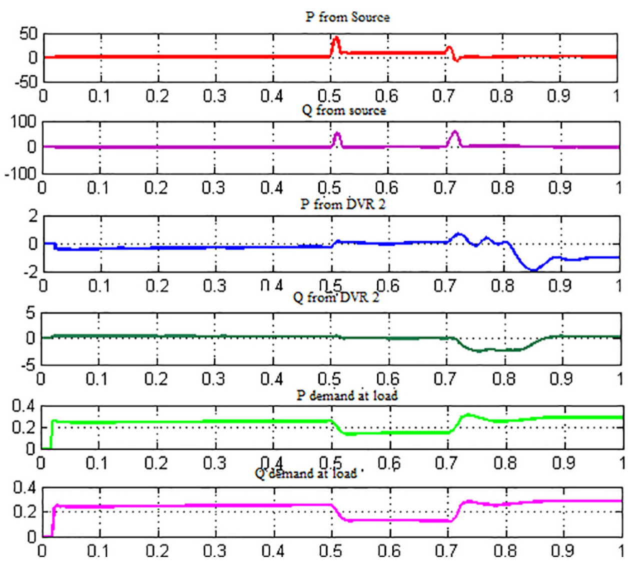

Fig. 7. Power Flow.

Table 2
Comparision between PSO and GSA.

Performance indices	PSO	GSA
$[K_p, K_i, K_d, \lambda, \mu]$	[109.7, 0.86, 1.76,0.46,0.97]	[101.2,0.67,2.32,0.12,0.78]
ISE	1.0868	0.7578
ITSE	2.7589	1.6289

Calculate velocity and update particles position

$$vel_{new} = rand(1) \times vel_{old} + acc(iter) \quad (7)$$

$$x_{new} = x_{old} + vel_{new} \quad (8)$$

Repeat steps 2-6 untill stopping criteria is reached

The final updated postion with best fitness is the global optimal solution

The GSA and PSO both have compromise characteristics to solve the complex non linear problems. Exploitation is the major difference between PSO and GSA. PSO has exploitation based on gbest. GSA has its local exploitation capability.

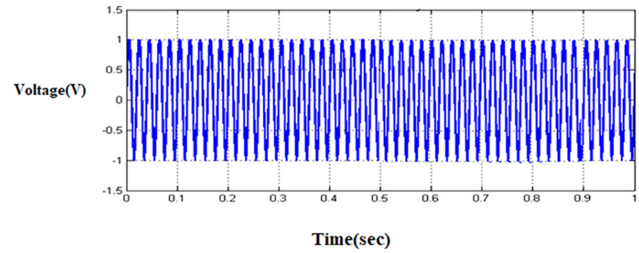

Fig. 8. Compensated load voltage.

4. Results and discussion

The two line IDVR is simulated in MATLAB/Simulink. The parameters for the simulation are shown in Table 1. The simulink diagram is shown in Fig. 2

Fig. 3 shows the source voltage and source current with 75% sag at 0.5s. The corresponding DC link compensating voltage is shown in Fig. 4. The FOPID controller compensates the load voltage at the instant voltage sag happens. The power quality is also ensured using this controller. The power factor and THD of source current is shown in Fig. 5 and. Fig. 6. respectively. The power flow between the source and the load is also shown in the Fig. 7 To demonstrate the effectiveness of the proposed algorithm, a comparision is made between PSO and GSA as shown in Table 2 . From the Table 2, it clearly reveals that the GSA based FOPID controller works efficiently on the IDVR system with minimum error Fig. 8.

5. Conclusion

A novel scheme of control for Interline dynamic voltage restorer (IDVR) is proposed based on optimized FOPID controller. The IDVR is modelled using two DVR system. The FOPID controller parameters are optimized using GSA with ISE and ITSE as the performance indices. The performance of our novel controller is evaluated by comparing the performance indices based on PSO algorithm. The GSA algorithm compensates the voltage sag with power quality enhancement.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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