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Mitigation of voltage sag/swell by dynamic voltage restorer using fuzzy based particle swarm controller

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ABSTRACT

Reliability of distributed system is measured with the power quality (PQ) that gains more interest of investigators and turned to be huge concern in commercial and industrial purposes. This work examined the voltage sag and swell problem and concentrates on improving the design of dynamic voltage restorer (DVR) for enhancing power quality. Here, a novel Fuzzy based Particle Swarm controller (F-PSC) is anticipated for reference DVR voltage creation. Here, various voltage injections are given for diminishing DVR rating and to enhance performance metrics like output power, size and cost. The anticipated model is provided for PQ sag and swell problem with MATLAB environment. While in compensation, output attained from DVR is compared with other controller model. Simulation outcomes validates that this controller provides economic solution for industrial requirements by offering compensation problems in shorter time duration.

1. Introduction

Generally, voltage sags/swells, interruptions, harmonics, transients are considered as diverse power quality problems associated with distributed systems [1]. The power quality crisis are triggered with adverse effects like addition and reduction of RMS and harmonic pollution peak value, heating, waveform, and reduced capacitors life, transformers, cables, controllers malfunction, premature distribution transformers failure, protective devices and relays [2]. This provides an extensive analysis towards PQ factors to determine various aspects of critical and sensitive loads and complete distribution system [3]. With huge PQ problems, voltage sags occurrence in supply lines provides roughly of 85% reported crisis that causes voltage reduction for power system. Voltage sags occur due to faults, transitional events and raised load demand like huge motor starting causes reduction in supply voltage RMS value for duration lesser than one minute; however higher than half supply cycle [4].

Mitigation is considered as an adverse influence in PQ distribution system influences users' awareness [5]. Therefore, it is needed to enhance reliability and power quality that are provided to users. A set of static devices are termed as customized power devices are rises from PQ problem solution. There are widely applied for load balancing, active filtering, voltage regulation and power factor correction [6]. Dynamic voltage restorer is a power devices to safeguards loads from voltage based poor quality and crucial consumer loads from loss and tripping, DVR in distribution system as IEEE 519 standards.

DVR has the competency for load voltage restoring to sinusoidal voltage with appropriate amplitude on distorted supply voltages [7]. It is a VSC based static model associated via transformer among load and supply to secure loads from sagging and therefore regulating load voltage [8]. Therefore, DVR is modeled and controlled to carry out diverse tasks by injecting compensating voltage waveform to distribution line [9]. The compensating voltage is given to DVR. When there is a SSC, no active power is provided to DVR [10]. However, in capacitor-based DVR, active power is needed to overcome VSC switching losses for regulating DC link. To reach pre-sag voltage, DVR absorb active power towards distributed system based on load type associated with the system.

Diverse control processes are analyzed based on various PI controller-based on current model control, p-q theory; instantaneous symmetrical components and so on are power device con-

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trols. Diverse optimization approaches like NN, fuzzy logic, and GA and PSO are analyzed in various studies [11]. The control process is used for switching VSC on optimization approach for reference voltage generation. PI controllers are utilized for controlling DVR [12]. DVR performance is based on PI gain tuning parameter values that are not optimized every time.

In this work, PI controller based parameters are optimized with the use of enhanced Fuzzy based PS approach for enhancing DVR performance. It is considered as a computational intelligence based optimization approach that has been inspired from biological organisms. MATLAB simulation is done with DVR supported capacitor for simulation and development to validate DVR performance under diverse voltage sag conditions.

2. DVR circuit model

Here, DVR is modeled to provide loads from severe voltage sagging. It is connected with load bus series and essentially huge voltage is needed to deal with voltage sagging. Initially, there are three phase supply that is needed for sensitive loads devoid of DVR devices. $V_{sca}, V_{scb}, V_{scc}$ are three supply voltage phase that specifies a, b and c respectively. $Z_{la}, Z_{lb} and Z_{lc}$ are line impedance. $V_{ta}, V_{tb} and V_{tc}$is terminal supply voltage for all phases and $V_{la}, V_{lb} and V_{lc}$ are load voltage. Sensitive loads are either unbalanced or balanced which is connected with load bus during the absence of DVR then load voltage is equal to terminal supply voltage.

DC link capacitor voltage controller model is used for linking and designing control towards DC link voltage effectually. Fuzzy model checks voltage sag in terminal supply voltage and functions as detector switch [13]. It holds threshold and load voltages relating voltage sag values. When sag is identified in load bus with supply voltage value, it identifies sagging in supply voltage and activates DVR control for sag compensation [14]. DVR control is based on versatile to resolve unbalance and dip components towards supply voltage with zero components. The DC link controlling challenge is based on DVR output as main control feedback. This may shows lesser complex than control [15]. The controller leads to complexity based on controlling effort to reduce system performance. The contribution towards this work is the self-designed control model with fuzzy system for eliminating power quality problem like unbalanced and balanced voltage sagging for sensitive loads; fuzzy has to eliminate sagging where DC capacitor voltage controller is used (Fig. 1. Fig. 2).

$$V_{la} = V_{ta} \tag{1}$$

$$V_{lb} = V_{tb} \tag{2}$$

$$V_{lc} = V_{tc} \tag{3}$$

Terminal supply voltage suffers from sag owing to transients and faults to load and to eliminate sensitive loads. DVR injects voltage in serried with terminal supply voltages. Here, DVR has to inject appropriate voltage differences as it presents in nominal load voltages and terminal supply voltages.

$$V_{la} = V_{ta} + V_{DVRa} \tag{4}$$

$$V_{lb} = V_{tb} + V_{DVRb} \tag{5}$$

$$V_{lc} = V_{tc} + V_{DVRc} \tag{6}$$

DVR is associated with components like DC link capacitor, voltage source converter and filters series with load bus via I_T. R_f and C_f are combined with secondary region of series transformer which functions as a filter for unwanted noise signal from injected voltages. C_{Dc} is DC link capacitor, L_c is coupling indicator, VSC_{DVR} is voltage source converter. The transformer power rating and VSC is based on voltage values and line current. However, coupling indicator value is based on modulation index, switching frequency, and VSC ripple current.

In ideal scenario, terminal supply voltage is based on load voltages for transformer to isolate among load bus and VSC_{DVR} where sag presence is due to supply voltages and transformer acts as a series voltage among load voltage and terminal supply voltage. With the control theory significance, appropriate DC link capacitor size plays essential role in voltage sag mitigation operation.

3. Fuzzy based computation

Fuzzy based controller performance is superior to logical operators during judgment capabilities when needed. It is of two link and dependent factors termed as data parameter and rule define parameter. The factors are based on essential role in determining capabilities. With fuzzy control, an automatic search is constructed and to command significant control based on voltage sagging at voltage supply point. The fuzzy model is based on numerical values that are determined with rule define parameter.

The input data to fuzzy control is based on RMS voltage values depicted with fuzzy parameter; this is an essential part of fuzzy

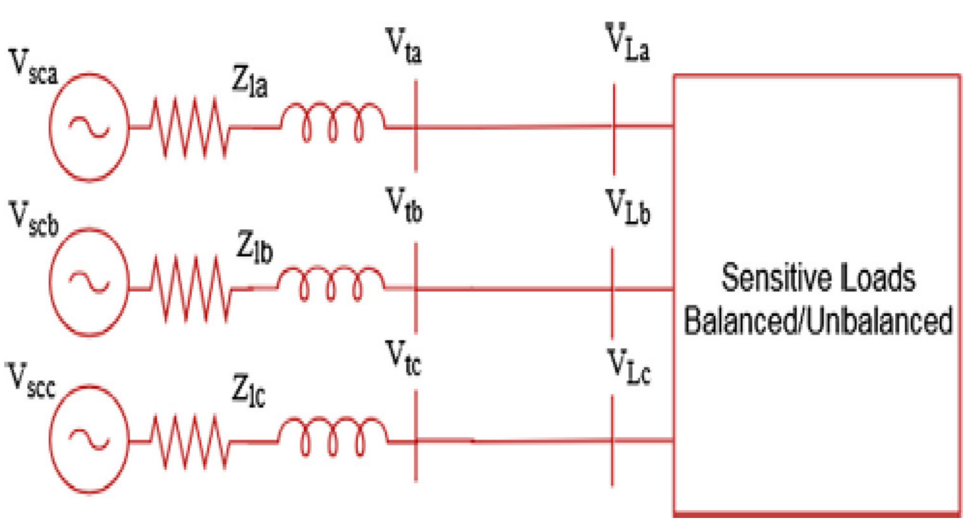

Fig. 1. Three phase circuit without DVR.

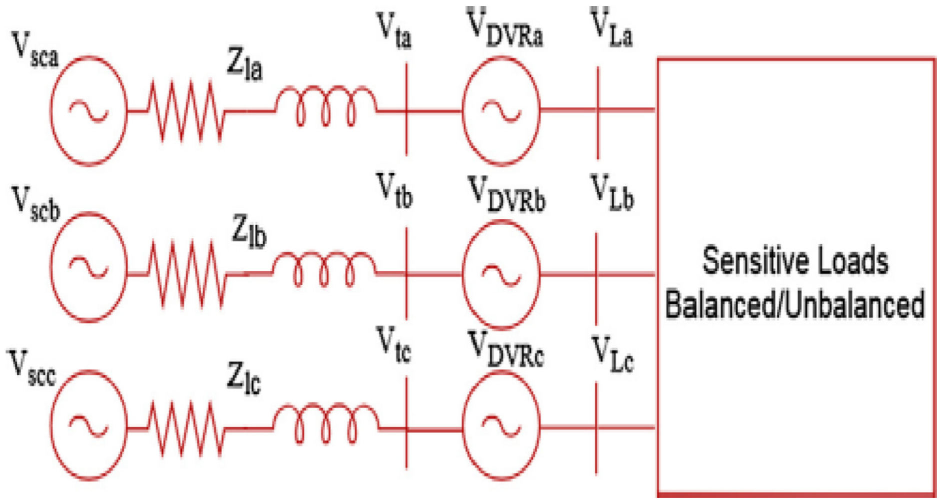

Fig. 2. Three phase circuit with DVR.

model as voltage sagging threshold decision with terminal voltage values. Threshold values for fuzzy control based output signal are determined with data defined parameter. Output signals may works on ON signal for essential control/output signals works on OFF signal. When signal is given to main control then activate compensate sag.

4. Particle swarm based controller

When PSO is executed, acceleration constant selection, inertia weights, maximal velocity limits are considered for swarm augmentation and to promote particle convergence for providing optimal solution. Here, PSO is provided with non-linear inertial weight and changing coefficients with superior gain parameters tuning in PI controller. Therefore, to reduce objective function with error criteria in performance index, MSE is known as performance index. Integral and proportional gain parameters of PI controller may show two pair of control variables for DC and AC link voltages.

Here, PSO is utilized for control variables optimization. Here, variables are given as particles. It gives swarm particles with appropriate time interval with minimal value known as lower bound and maximal value termed as upper bound of controller variables. Therefore, multi-parameter is designed for coded variables with its own bounds. The controller pairs are needed for realization. PSO is to offer optimal controller performance. This optimization approach is determined to be a multi-objective opti-

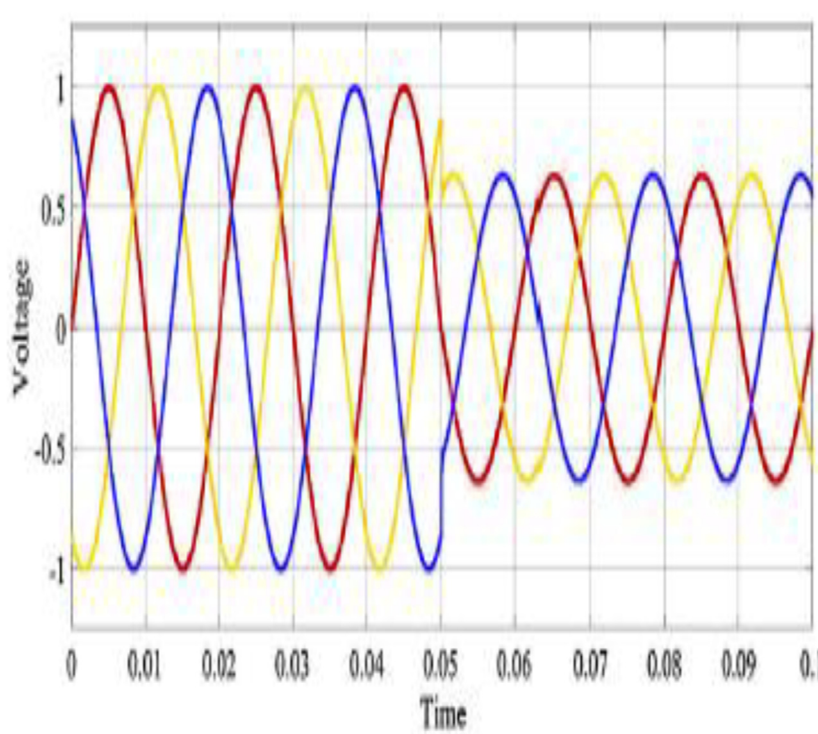

Fig. 3. Balanced voltage sag with load bus voltage.

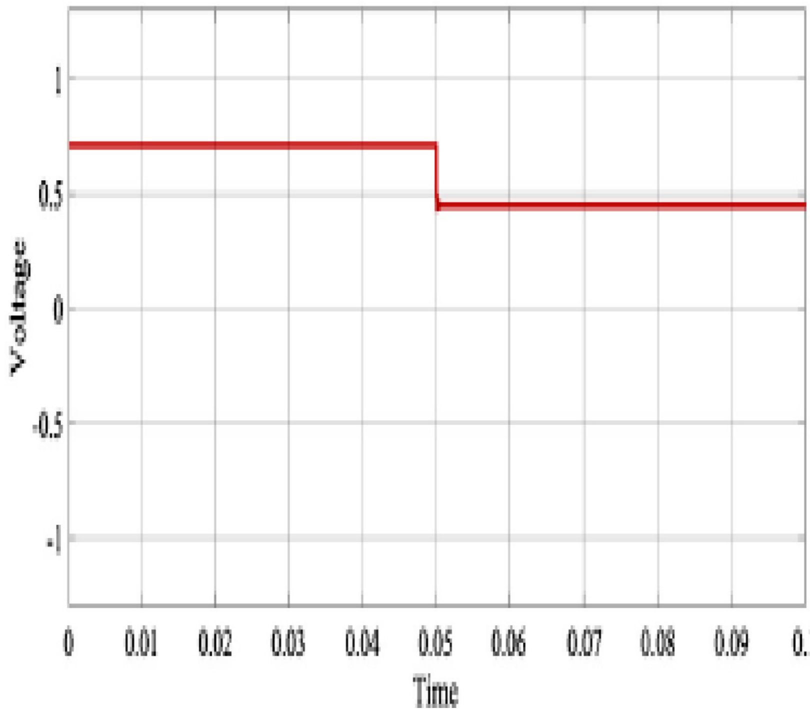

Fig. 4. Sag RMS.

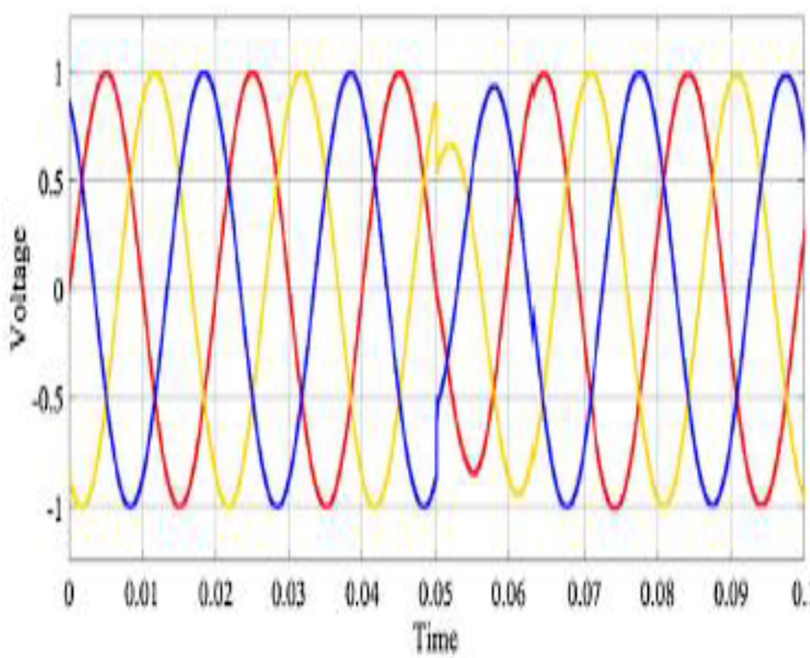

Fig. 5. Balanced sag compensation.

mization for enhancing operating condition adaptability and DVR performance.

4.1. Tuning control variables with PSO

The control variables upper/lower bounds are determined and array of particle population is initialized. Swam may have random particles with dimension generated.

$$K_i(t) \in [K_{min}, K_{\max]whereK_{min}} = [K_{p1\min} k_{i1\min} k_{p2\min} k_{i2\min}] \quad (7)$$

$$K_{-}\max = [k_{p1max}, k_{i1max}, k_{p2mac}, k_{i2\max}]; \quad (8)$$

Velocity range is provided as

$$v_i(t) \epsilon [V_{min}, V_{max}] \quad (9)$$

Acceleration parameters are provided as:

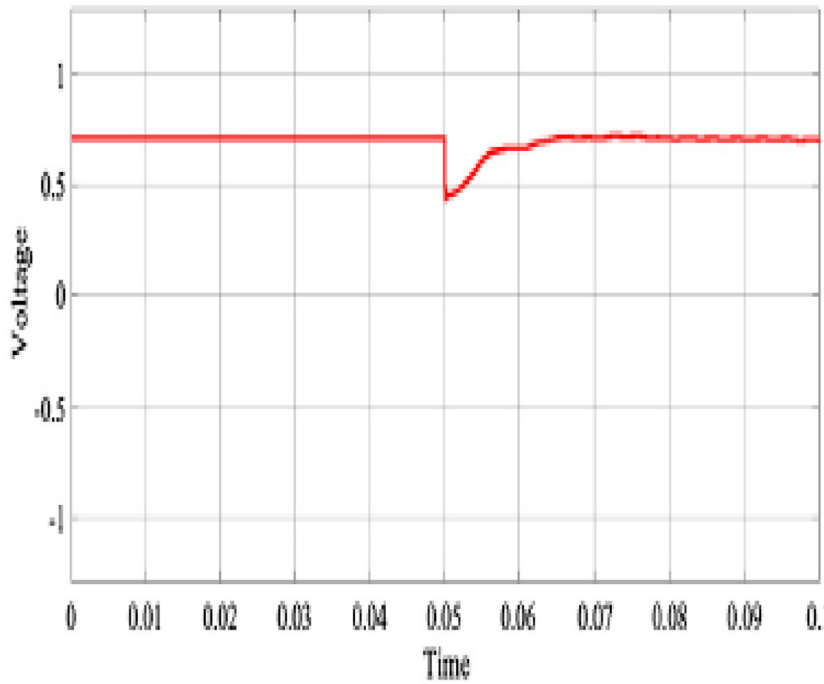

Fig. 6. Balanced sag compensation RMS.

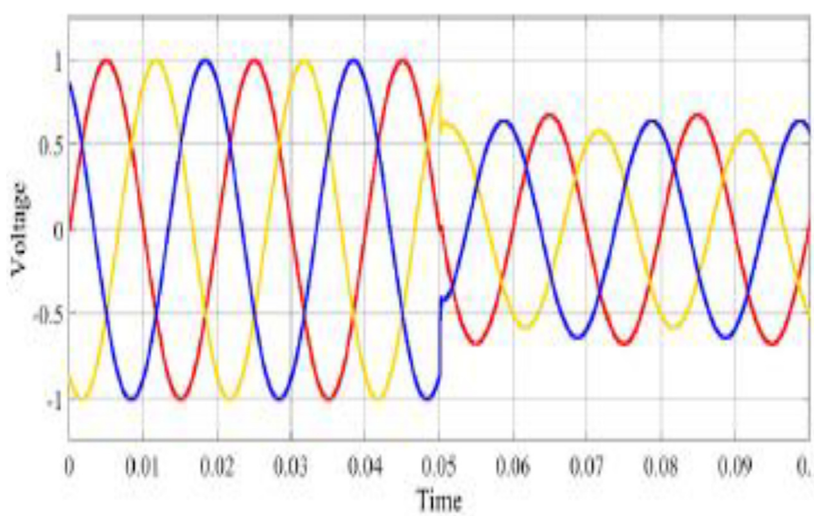

Fig. 7. Imbalanced sag load bus voltages.

$$C_1 = C_2 = 2; r_1, r_2 \epsilon [0, 1] \tag{10}$$

Maximal number of iterations is provided as

$$Swarm = \begin{bmatrix} swarm_1(t) \\ swarm_2(t) \\ . \\ . \\ swarm_i(t) \end{bmatrix} \tag{11}$$

$$v = \begin{bmatrix} v_1(t) \\ v_2(t) \\ . \\ . \\ v_i(t) \end{bmatrix} \tag{12}$$

Where $K_i(t) = swarm_i(t)$

Computation of fitness function is determined by ISE and fitness value evaluation of current iteration is based on particle swarm. This may offer objective function measures fitness value of all particles where swarm size is provided by number of particles. Particle fitness value based comparison is done with individual particle with pbest. It may validate fitness value with finest position of every particle as:

$$J_i(t) > J_{pbest}(t); then J_{pbest}(t) = J_i(t) \tag{13}$$

$$pbest_i(t) = swarm_i \tag{14}$$

The fitness value is termed as $J_{pbest}(t)$; and superior evaluation between $J_{pbest}(t)$ is termed as $J_{gbest}(t)$. Fitness value is provided with a group of best position of all particles gives:

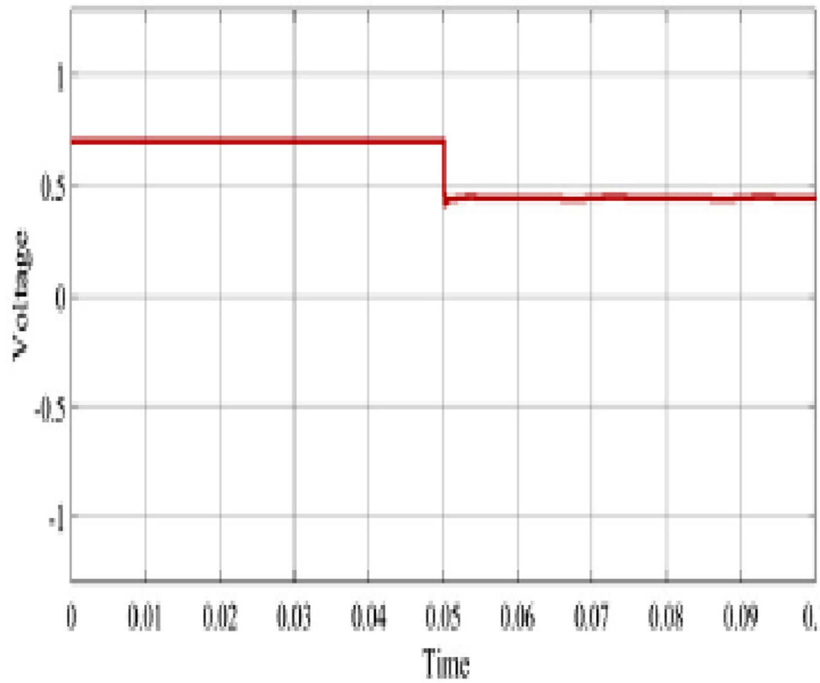

Fig. 8. Sag RMS.

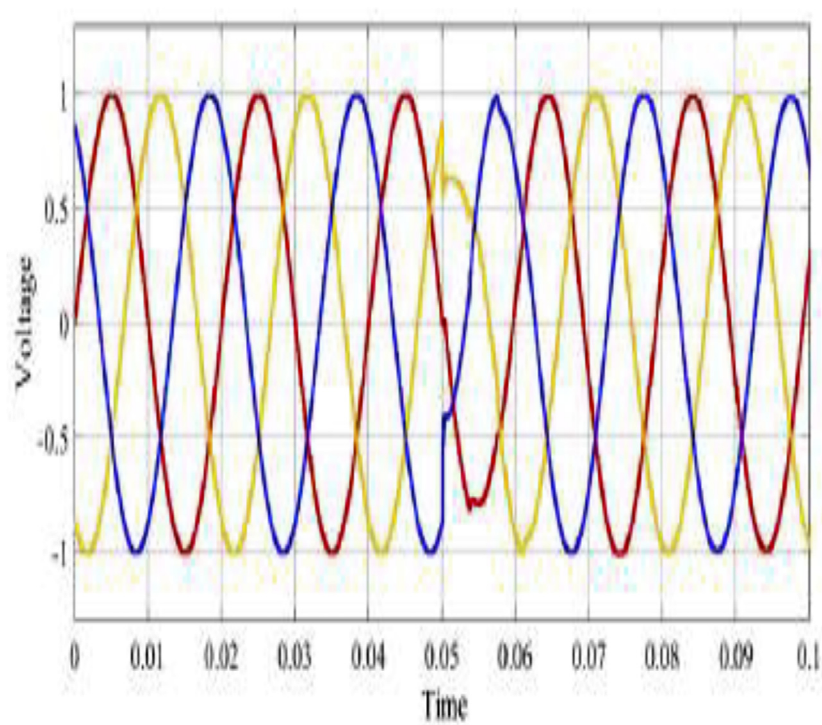

Fig. 9. Imbalanced sag compensation.

$$gbest_i(t) = swarm_i \tag{15}$$

The particle velocity based updation and position is based on Eq. below. Inertia weight is provided as in Eq. ():

$$w(k) = (W_{max} - \ W_{min}\ ) * \tan\left(\frac{7}{8}\right) * \left(1 - \left(\frac{t}{iter_{\max}}\right)^P\right) + W_{\min} \tag{16}$$

Here, $iter_{max} = maximal' t' value$

Imposition of restriction condition on particle velocity is provided as in Eq.(17):

$$v_i(t+1) = \begin{cases} v_{max} & v_j(t+1) > v_{max} \\ v_j(t+1) v_{min} & v_i(t+1) \le v_{max} \\ v_{min} v_j(t+1) & v_{min} \end{cases} \tag{17}$$

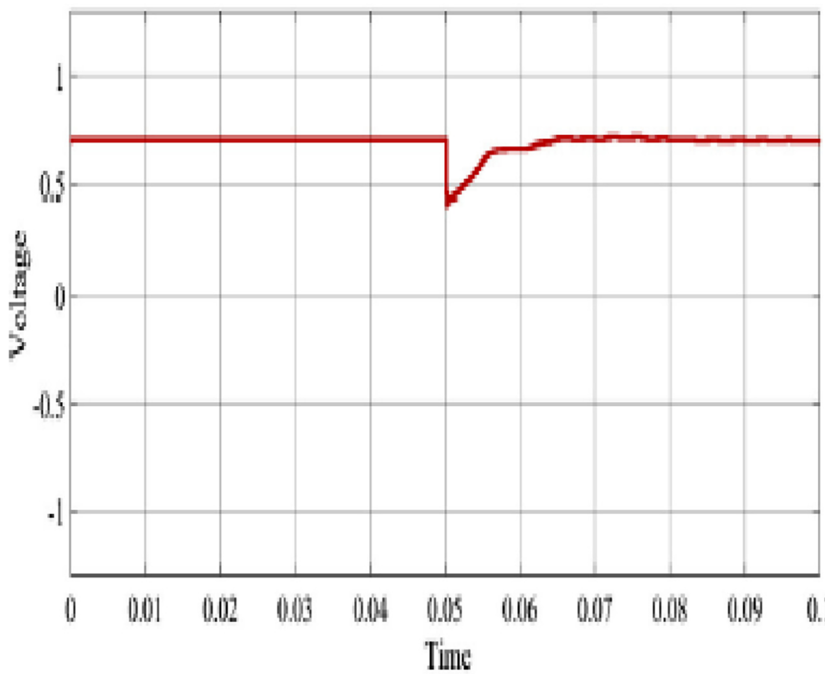

Fig. 10. Imbalanced sag compensation.

Table 1
Parameters of the proposed F-PSC for simulation.

Parameters	Value
Phase voltage	220 V
Line frequency	1p.u
Line impedance	50 Hz
Balanced load	0.3 Ω
Unbalanced load	2.15 + j1.3p.u
Turn ratio	1.15 + j2.2p.u
R_f	0.65 Ω
C_f	85 μF
L_c	0.72 mH
DC link capacitor	7590 μF

$$k_j(t+1) = \begin{cases} k_{max}, k_j(t+1) > k_{max} \\ k_j(t+1)k_{\min \le k_j(t+1) \le k\_\max} \\ k_{\min k_j(t+1)} < k_{min} \end{cases} \quad (18)$$

Based on certain crisis, there are diverse termination condition is chosen based on maximal number of iterations; certain search position has to fulfill pre-determined minimal threshold. Finally, terminate the process and provide optimal solution.

5. Simulation results

The simulation is done with MATLAB simulation environment. Here, a particle swarm based controller model is used by DVR system.

Figs. 3–6 shows the terminal supply voltage point over balanced sag condition devoid of DVR compensation. It works under normal operation and maintains 1p.u voltage. RMS terminal value is provided based on supply voltage under balanced condition. The balanced sag compensation is also provided with RMS value. Figs. 7–10 shows the terminal supply point voltage based on imbalanced sag condition devoid of DVR compensation with 0 s to 0.05 s grid that operates under normal condition and maintains 1p.u. Terminal supply voltage based RMS value is also considered under imbalanced sag condition. Table 1 shows the parameter setup of proposed model.

6. Conclusion

Voltage sag and swell is considered as a superior power quality factor that influences sensitive load among distributed system. Here, controller system is designed based on fuzzy and particle swarm optimization model to determine the balanced and unbalanced voltage sag under distributed system. The controller model is used to determine the distribution power and to examine the switching factor of DVR.

CRediT authorship contribution statement

S. Sudharani: Conceptualization, Data curation, Methodology, Resources, Software, Investigation, Visualization, Writing - original draft, Writing - review & editing. **D. Godwin Immanuel:** Conceptualization, Methodology, Investigation, Resources, Visualization, Supervision, Writing - original draft, Writing - review & editing.

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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