A novel optimization-based power quality enhancement using dynamic voltage restorer and distribution static compensator

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ABSTRACT

The power assurance for distinct purchaser in the nation must be guaranteed through electric power distribution (EPD) system, subsequently EPD must be reliable, and well facilitating with power quality (PQ) in distribution framework. It will be much significant to keep up with PQ in power distribution (PD) framework for service continuity. The PQ issue basically emerge in distribution framework are voltage swell, sag, harmonics, and disparities in power. In this manuscript, the PQ development in photovoltaic (PV) PD framework for IEEE 33 and 57 bus frameworks is deliberated as the aim. The improvement is satisfied with FACTS pay gadgets of dynamic voltage restorer (DVR) and distributed static compensator (DSTATCOM). The butterfly optimizer (BO) and gray wolf optimizer (GWO) framework is deliberated for suggested work that implies a switching gadget and it compares the yield signal of DSTATCOM and DVR. In this proposed system DVR is compensated with an advanced GWO and DSTATCOM with BO for optimal location of FACTS devices in IEEE 33 and 57 bus systems are discussed like in the conventional paper as 13th bus for IEEE 33 system & 30th bus for IEEE 57 system.

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1. INTRODUCTION

The proposed paper mainly focused on improvement of power quality in all aspects of irregular load conditions using best optimal location and control with butterfly optimizer (BO) [1], monarch butterfly optimization (MBO) [2] and gray wolf optimizer (GWO) [3] techniques. The power quality (PQ) works with voltage variations, recurrence variety, drifters, and other nonlinear load-related issues [4]. The "reactive power (RP)" is genuine concern prompts to go crazy of power framework. In a couple of conditions receptive current prompts to influence adversity problems to more conspicuous grow [5]. The PQ problem in delicate and non-direct load is remunerated with guide of "flexible alternating current transmission system (FACTS)". The implementation of power distribution (PD) framework grows the nature of control through compensation gadgets [6]. These pay gadgets added at reason behind normal coupling and commendably upgrade PQ. The bending in alternating current (AC) mains might be reduced by uniquely assembled 3-phase "multi-phase alternating current direct current converters (MPC)" [7]. This compensator is expected to work with each unique "distribution generation (DG)" framework in which two four-phase leg inverters have been utilized to update the PQ inside the framework [8]. The PQ at medium voltage appropriation level is upgraded by custom power devices (CPD) explicitly distributed static compensator (DSTATCOM) and dynamic voltage restorer (DVR). The voltage swell, sag is decreased by series associated gadget to be specific DVR [9]. Single stage bound together power flow conditioners eliminate PQ issues such as voltage harmonics, swells, sags, load receptive power, and voltage flash in single stage structures [10]. The optimization methods are the novel techniques for acquiring PQ with further developed power factor, diminished power loss and ideal DG-unit size [11]–[14].

The MBO [15] is used for identifying the optimum location for installing of DSTATCOM is portrayed in this manuscript. To produce an ideal outcome with DVR framework we utilize PI controller alongside it [8]. The PI controller is for all time utilized controller among all recognized controller in modern work [9]. To detect and sense the generating voltage and maintain it at a specific level, a DVR framework with a PI controller was used [10], [11]. The PI controller with DVR assumes an incredible part to improve the generator yield voltage reaction, increment the framework soundness and PQ to fulfill the shopper needs and requests. Additionally, the tuning of a PI controller with DVR is altogether a moving undertaking to perform. A few methods are propounding to coordinate with the PI controller boundary [12]. This power integrity (PI) controller boundary is nattily streamlined by utilizing different delicate processing and customary methods like particle swarm optimization (PSO) PI, ZN-PI, MOL-PI, and GWO [16], [17] PI. To choose a superior calculation, many elements are being seen like execution investigation, cost capacity and PQ [18]–[20]. For improving PQ either voltage control or current control techniques [21] or both can be used where ever required. For improving voltage profile and PQ DG’s are connected in with hybrid controllers [22], [23]. For identifying the suitable location to connect controller there are several optimization techniques [24]–[27] were used. In this manuscript, the suggested GWO calculation has been depicted, created by Mirjalli *et al.* 2014, emulates the administration chain of command of wolfs which are known for their gathering hunting. The GWO procedure generally utilized in 3 phases; i) encircling, ii) searching, and iii) hunting. The simulation outcomes contrasted and different calculations with further developed reactions. In this manuscript, suggested MBO method had been portrayed that depends on behavior of migration conduct in nature [11]. Two phases are deliberated in this process. The first phase uses the migration operator to show the butterfly's motions from one location to the next. In the 2^{nd} phase, location of different butterflies is changed by fluctuating the administrator. The recreation consequences of suggested strategy present best outcomes in contrast with other optimization procedures and develop step reaction of generator terminal voltage. In following segment, framework displaying of DSTATCOM has portrayed.

2. PROPOSED METHODOLOGY

The EPD framework with improved dependability and constant supply is a definitive framework for dispersion of power. The PQ problems might be extreme by deliberating utility side and client side. The PQ problems are removed by focusing on 2 methodologies specifically load conditioning that guarantees that device is low sensitive to power conflicts, permitting the activity of device in a productive way much under huge voltage mutilation. The block diagram of proposed method is shown in Figure 1. The following methodology comprises of line conditioning frameworks, which suppress the remunerate load power factor and line current harmonic. In our suggested framework the wind power distribution framework has been considered with DVR and DSTATCOM based IEEE 33 and 57 bus frameworks to alleviate PQ issue. The PQ problems like voltage swell, sag, and variation of frequency have been deliberated. The compensators have been driven by GWO controller. The GWO controller estimates value of error among set point and real value. To restrict the error, the controller uses a control variable. The tuning is done using the dragon fly method, with the set point connected to the compensator. The high compensation voltage is selected by the comparator and driven to the yield load area.

2.1. Modeling of DSTATCOM

DSTATCOM comprises of VSC, a dc energy storage gadget, a coupling transformer (CT) associated in shunt to distribution network through CT [24] is shown in Figure 2. Appropriate change of phase and size of DSTATCOM yield voltages viably control active and reactive power trades among AC and DSTATCOM framework. The VSC is associated in shunt way that is utilized for 3 requirements are power factor correction, RP compensation, and current harmonics reduction.

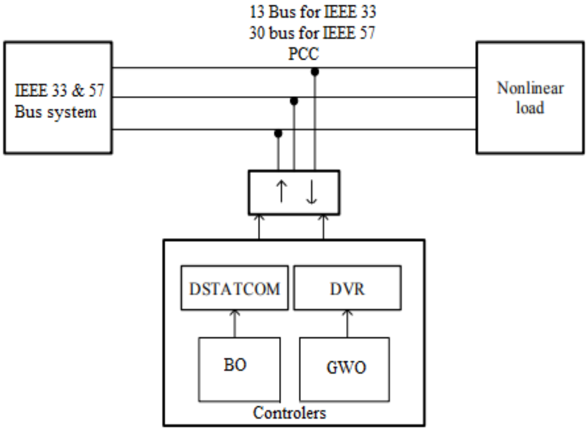

Figure 1. Simple block diagram for DVR and DSTATCOM with BO & GWO integrated system

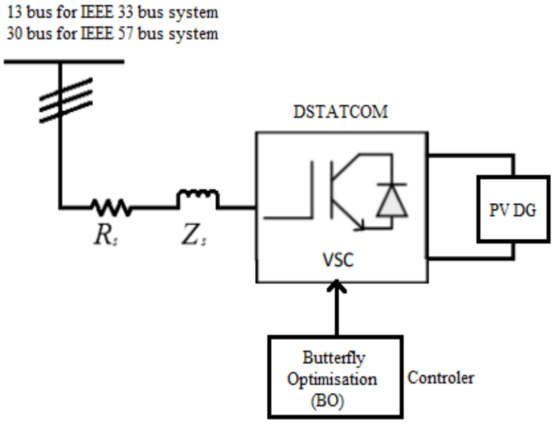

Figure 2. Configuration of DSTATCOM

The terminal voltage has been calculated as (1):

$$\boldsymbol{V_t} = \sqrt{\frac{2}{3}(\boldsymbol{V_a^2} + \boldsymbol{V_b^2} + \boldsymbol{V_c^2})} \tag{1}$$

the in-phase units have been calculated as (2):

$$\boldsymbol{V_{ina}} = \frac{\boldsymbol{V_a}}{\boldsymbol{V_t}}\,; \boldsymbol{V_{inb}} = \frac{\boldsymbol{V_b}}{\boldsymbol{V_t}}\,; \boldsymbol{V_{inc}} = \frac{\boldsymbol{V_c}}{\boldsymbol{V_t}} \tag{2}$$

quadrature units have been calculated as (3):

$$V_{qa} = \frac{-V_{inb} + V_{inc}}{\sqrt{3}} \tag{3}$$

$$\boldsymbol{V_{qb}} = \frac{(\sqrt{3}\boldsymbol{V_{ina}} + \boldsymbol{V_{inb}} + \boldsymbol{V_{inc}})}{\sqrt{2}\sqrt{3}} \tag{4}$$

$$\boldsymbol{V_{qc}} = \frac{(\sqrt{3}\boldsymbol{V_{ina}} + \boldsymbol{V_{inb}} - \boldsymbol{V_{inc}})}{\sqrt{2}\sqrt{3}} \tag{5}$$

the load current for every phase is attained by subsequent formulas:

$$\boldsymbol{I_{la}} = \boldsymbol{I_b} \sin(\boldsymbol{\omega T} - \boldsymbol{\phi}) \tag{6}$$

$$\boldsymbol{I_{lb}} = \boldsymbol{I_b} \sin(\boldsymbol{\omega T} - \boldsymbol{\phi} - \frac{\boldsymbol{2\pi}}{\boldsymbol{3}}) \tag{7}$$

$$\boldsymbol{I_{lb}} = \boldsymbol{I_b} \sin(\boldsymbol{\omega T} - \boldsymbol{\phi} + \frac{\boldsymbol{2\pi}}{\boldsymbol{3}}) \tag{8}$$

in DC, the real and reactive power components could be written as (9) and (10).

$$\boldsymbol{P_d} = \boldsymbol{P_l} - \boldsymbol{P_1} \tag{9}$$

$$\boldsymbol{Q_d} = \boldsymbol{Q_l} - \boldsymbol{Q_1} \tag{10}$$

The active load power and the oscillating component of real power, respectively, are P_l and P_1. Q_l and Q_1 are the instantaneous reactive load power and the oscillation component of RP. The final load and RP equation are as:

$$\boldsymbol{P_{load}} = \boldsymbol{V_t}(\boldsymbol{I_{la}}\boldsymbol{V_{ina}} + \boldsymbol{I_{lb}}\,\boldsymbol{V_{inb}} + \boldsymbol{I_{lc}}\boldsymbol{V_{inc}}) \tag{11}$$

$$Q_{load} = V_t(I_{la}V_{qa} + I_{lb}V_{qb} + I_{lc}V_{qc}) \quad (12)$$

as a result, the loading injection parts have been methodologized. The source current active power modules are provided by (13) and (14).

$$I_{s1} = \frac{2P_{load}}{3V_t} \quad (13)$$

$$I_{s2} = k_p v_e + k_i \int v_e \mathrm{d}t + k_d \frac{d}{dt}(v_e) \quad (14)$$

The active component amplitude of reference source current is (15).

$$I_{samp} = I_{sp} + I_{sq} \quad (15)$$

The following is an assessment of the active power component of an active power source.

$$I_{sa}^{*} = I_{samp}{}^{*} v_{ina} \quad (16)$$

$$I_{sb}^{*} = I_{samp}{}^{*} v_{inb} \quad (17)$$

$$I_{sc}^{*} = I_{samp}{}^{*} v_{inc} \quad (18)$$

RP component of reference current.

$$I_{qa}^{*} = I_{slamp}{}^{*} v_{qa} \quad (19)$$

$$I_{qb}^{*} = I_{slamp}{}^{*} v_{qb} \quad (20)$$

$$I_{qc}^{*} = I_{slamp}{}^{*} v_{qc} \quad (21)$$

The final reference current is provided in (22)-(24).

$$I_{sra}^{*} = I_{sa}{}^{*} v_{ina} \quad (22)$$

$$I_{srb}^{*} = I_{sb}{}^{*} v_{inb} \quad (23)$$

$$I_{src}^{*} = I_{sc}{}^{*} v_{inc} \quad (24)$$

The current signals above were obtained as a result of the "DSTATCOM compensator." This yield is supplied into the comparing unit for extra power framework compensation [21].

2.2. DSTATCOM control monarch butterfly optimization

The behavior of monarch butterflies during their migration across North America inspired the work [22]. In MBO, a singular's search direction is described by two views. Butterfly adjusting operator (BAO) i) and migration operator ii) two subpopulation sets result from dividing the overall population (NP) into subpopulation1 (NP1) living in Land1 and subpopulation2 (NP2) living in Land2. migration operator (Pseudo code).

```
Begin
    for y=1 to NP1
      for z=1 to dim
        r1 = rand*period, where rand~U(0,1)
        if r1 ≤ p1 then
            xy,z = xr2,z , where r2~ U[1,2,…,NP1]
        else
            xy,z = xr3,z , where r3~ U[1,2,….,NP2]
        end if
      end for
    end for
End.
```

Where dim denotes population size; p1 is the monarch butterfly ratio in Land1 (p1 = 5/12); and period denotes the migration duration (period = 1.2). The population size in a 30-bus framework is 100, and the number of maximum iteration cycles (Tmax) is 200, but the population size in a 118-bus system is 50, and the number of maximum iteration cycles (Tmax) is 500.

```
Begin
    for p=1 to NP_2
        for d=1 to dim
            if rand ≤ p_1 then      where rand~U(0,1)
                x_p,d = x_best,k
            else
                x_p,d = x_r4,j       where r4~U[1,2,…,NP_2]
                if rand > BAR then
                    x_p,d = x_p,d + w_f*(dx_d – 0.5)
                end if
            end if
        end for
    end for
End.
```

Where wf = Smax/t2 denotes the weighting factor, Smax denotes an individual's maximum single-step walk step (Smax = 0.4), and t denotes the current iteration number; BAR = 5/12; walk step is denoted by dx of monarch butterflies that can be attained by performing Levy flights [22], [23], and step size is denoted by:

$$\text{StepSize} = \text{ceil}\ (\text{exprnd}\ (2{*}T_{max})) \tag{25}$$

where Tmax denotes the maximum number of iterations, and exprnd(x) generates exponential random numbers with mean x.

2.3. Modeling of DVR

DVR is a currently suggested series associated strong state gadget that infuses voltage into the framework to control load side voltage. It is typically introduced in distribution framework among the critical load and supply feeder [9] as displayed in Figure 3. Normally the association is made through transformer; however configurations with direct association via power gadgets additionally exist. The subsequent voltage at heap transport bar equivalents to the amount of the matrix voltage and infused voltage from DVR. The converter creates the RP required while the active power has been taken from storage of energy. The storage of energy might be distinctive relying upon compensating requirements. The DVR frequently has limits on duration and depth of voltage dip, which might compensate [11].

Infusing/engrossing RP could be used to compensate for power sags while using a DVR. Compensation is achieved by infusing RP while the infused voltage is in quadrature with current at major recurrence, and DVR is capable of producing the RP because DVR is self-upheld with dc bus. The control process should take into account limits such as voltage infusion capability (inverter and transformer ratings) and energy storage size improvement [13].

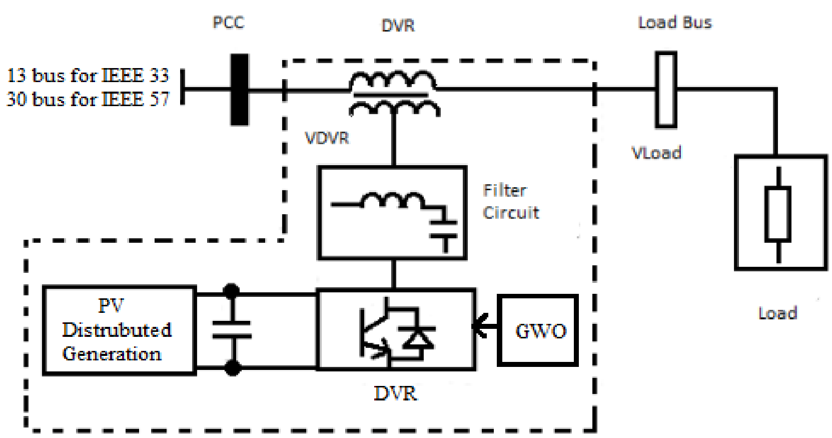

Figure 3. DVR series connected topology

2.4. DVR controller, mathematical model grey wolf (GWO)

This segment describes the mathematical method of hierarchy containing of encircling, searching, and attacking.

– We shall refer to alpha as the fittest outcome, beta &delta as the second and third solutions, and omega as the final solution [15].
– Encircling prey Mathematical mode of encircling the pray is described in (26) and (27).

$$\overline{D} = |\overline{C}\ \overline{X_P}(t) - \overline{X}\ (t)| \tag{26}$$

$$\overline{X}\ (t+1) = |\overline{X}\ (t) - \overline{A}\,.\overline{D}| \tag{27}$$

– The vector coefficients A and C are vector coefficients, and the current iteration is t. Vector Xp & the letter X represents a grey wolf's stance. Estimation of the A and C & vector.

$$\overline{A} = 2\vec{a}\,.\overrightarrow{r_1} - \vec{a} \tag{28}$$

$$\overline{C} = 2\,.\overrightarrow{r_2} \tag{29}$$

– Hunting: This phase often refers to assessing the position of pray and following it until all wolves have surrounded it. The hunt was joined by alpha, beta, and delta, which all played a role in the hunting system. Presently the accompanying conditions have been anticipated for this regard [13].

$$\overline{D_\alpha} = |\overline{C_1}\,.\,\overline{X_\alpha} - \overline{X}\,| \\ \overline{D_\beta} = |\overline{C_2}\,.\,\overline{X_\beta} - \overline{X}\,| \\ \overline{D_\delta} = |\overline{C_3}\,.\,\overline{X_\delta} - \overline{X}\,| \tag{30}$$

$$\overline{X}_1 = \overline{X}_\alpha - \overline{A_1}\,.\overline{D_\alpha} \\ \overline{X}_2 = \overline{X}_\beta - \overline{A_2}\,.\overline{D_\beta} \\ \overline{X}_3 = \overline{X}_\delta - \overline{A_3}\,.\overline{D_\delta} \tag{31}$$

$$\overline{X}\ (t+1) = \frac{\overline{X_1} + \overline{X_2} + \overline{X_3}}{3} \tag{32}$$

– Attacking: During this part, the pray movement comes to a halt, and all of the wolves encircled pray as shown in Figure 4. In this mathematical strategy, we lower the value of a, so that the value of a falls inside the range [-2a, 2a]. Now comes the fun part:

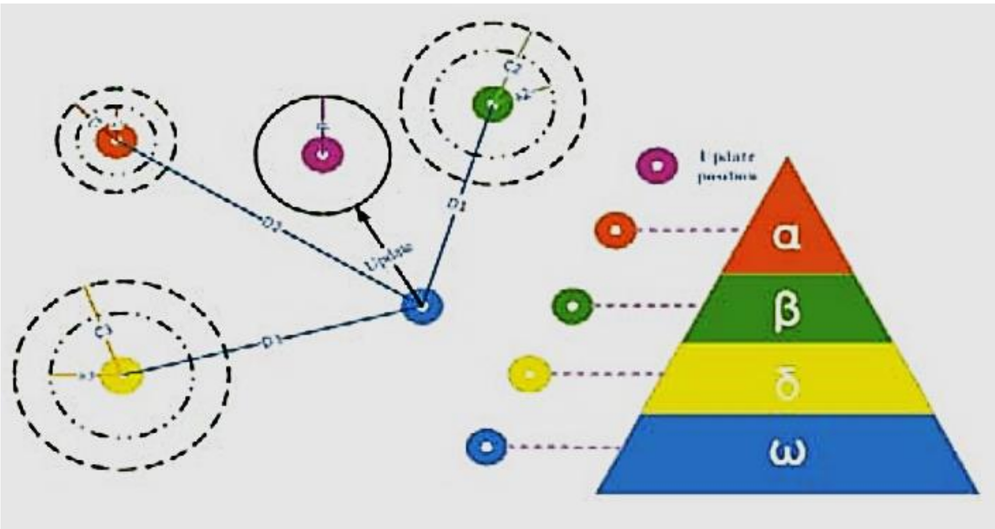

Figure 4. The attacking pray condition

– Searching for pray: This segment is simple to learn by the use of Figure 5 [15], [16].
Now the flowchart of GWO algorithm with all probabilities comprising all steps displayed in Figure 6.

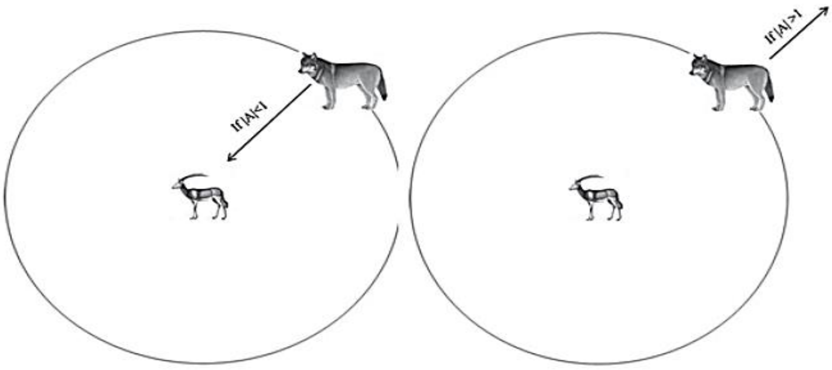

Figure 5. Attacking prey versus searching for prey

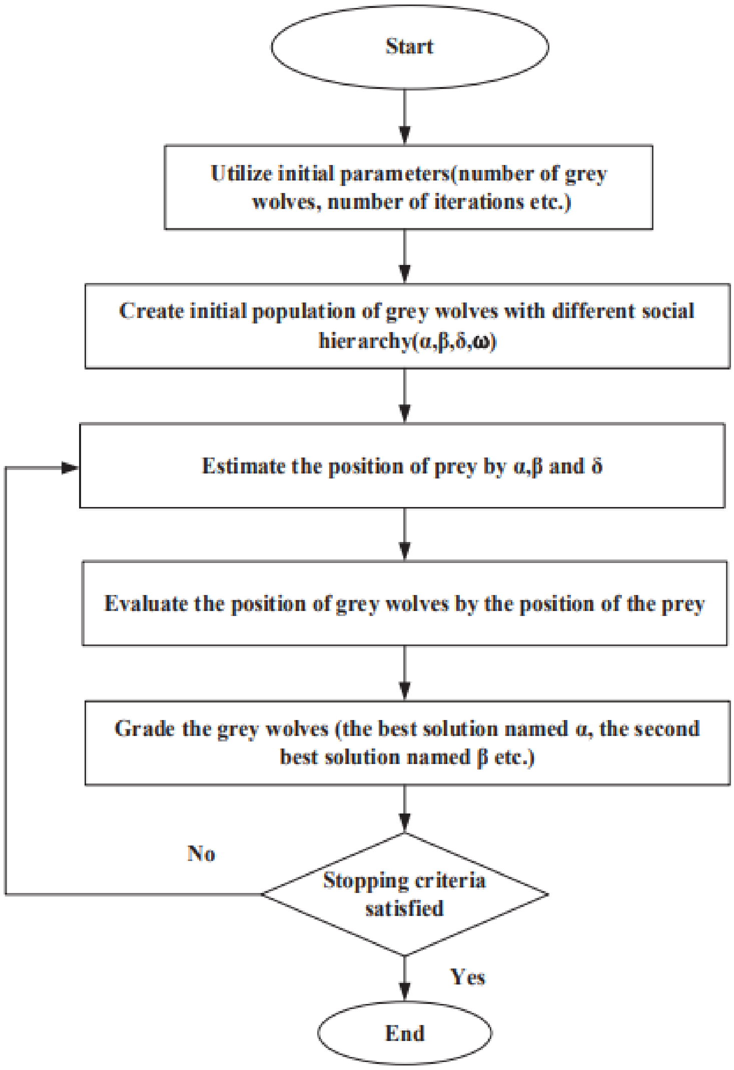

Figure 6. Flow chart of GWO algorithm

2.5. Matlab modeling and simulation

The MATLAB method of DVR connected system [7] for IEEE 33, 57 bus system at 13th bus & 30th bus respectively. Gray wolf optimizer GWO is used to give feed back to DVR for optimizing the fault voltages & compensate the sag & swells. The 3-phase programmable source has been associated with 3-phase load through DVR to produce swell, harmonic and sag in supply side. The DVR comprises of a DC Voltage source and PWM inverter circuit associated at DC Link of VSI. The D-STATCOM controls the voltages on the 13th and 30th buses by producing or absorbing RP. This RP transfer is accomplished across CT's leaking reactance by producing a secondary voltage in phase with the primary voltage (network side). |A voltage-sourced PWM inverter provides the voltage, and a Butterfly Optimizer provides the feedback (BWO). The Voltage profile with Sag voltage, GWO fed DVR & BO fed DSTATCOM injected voltage, Compensated Voltage at load for 57 bus shown in Figure 7. The voltage (Sag) profile before & after compensation for 57 bus is shown in Figure 8.

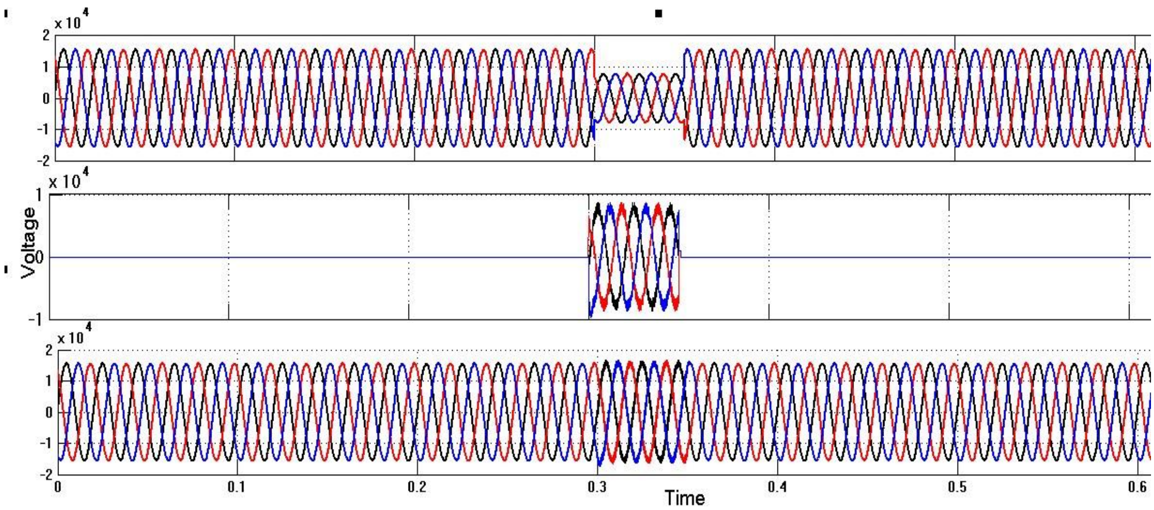

Figure 7. Voltage profile (Vabc): Sag voltage, GWO fed DVR & BO fed DSTATCOM injected voltage, compensated voltage at load for 57 bus

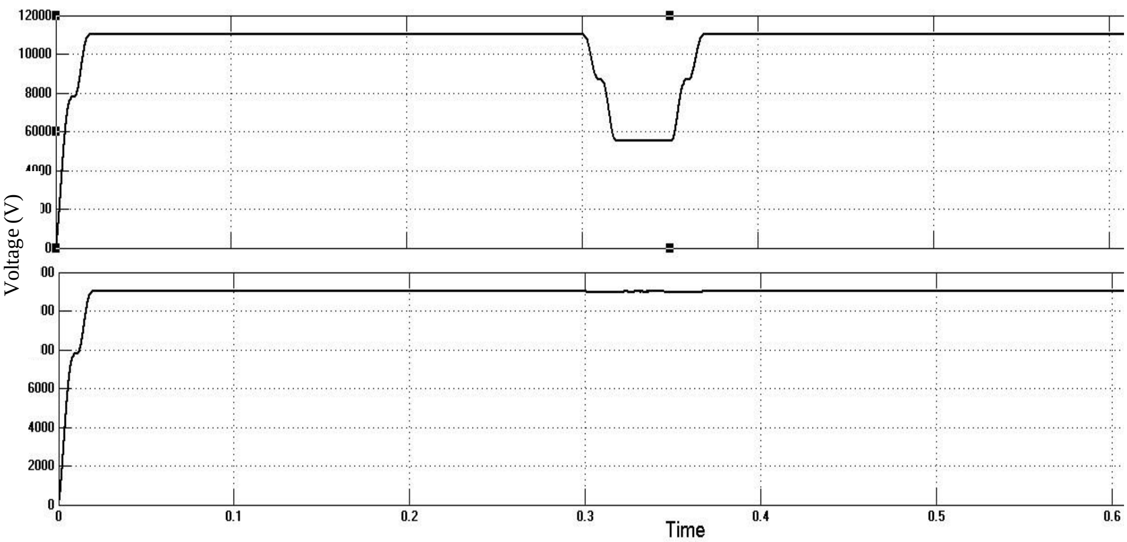

Figure 8. Voltage profile (Vrms): before & after compensation (Sag) for 57 bus

The simulation includes a GWO-fed DVR and a BO-fed DSTATCOM, as well as a 3-phase short-circuit fault at the ABC point, which is applied over a 200-ms period via a 0.66 fault resistance. In comparison to the reference voltage, the voltage sag at load point is nearly 20%. The DVR and DSTATCOM are simulated to be in operation solely for the period of the fault using the MATLAB tools. When compared to DG DSTATCOM, the fault settling time is lowered. The Voltage profile for GWO fed DVR & BO fed DSTATCOM injected voltage, compensated voltage at load for 57 bus is shown in Figure 9 and voltage swell before and after compensation for 57 bus is shown in Figure 10.

The simulation includes a GWO-fed DVR and a BO-fed DSTATCOM, as well as a three-phase short-circuit fault induced at the ABC point via 0.66 load resistance over a 200-ms time. In comparison to the reference voltage, At the load location, the voltage sag is nearly 20%. MATLAB tools are used to simulate the DVR and DSTATCOM operating solely for the length of the load. The fault settling time is reduced when compared to DG DSTATCOM. The simulation outcomes with settling time, THD, % of sag & swell for IEEE 33 & 57 bus for different compensators is given in Table 1. The THD of voltage sag for GWO fed DVR & BO fed DSTATCOM is 0.11% for 57 bus and the FFT Analysis is shown in Figure 11 and the THD for Voltage Swell is 0.41% for 57 bus is shown in Figure 12.

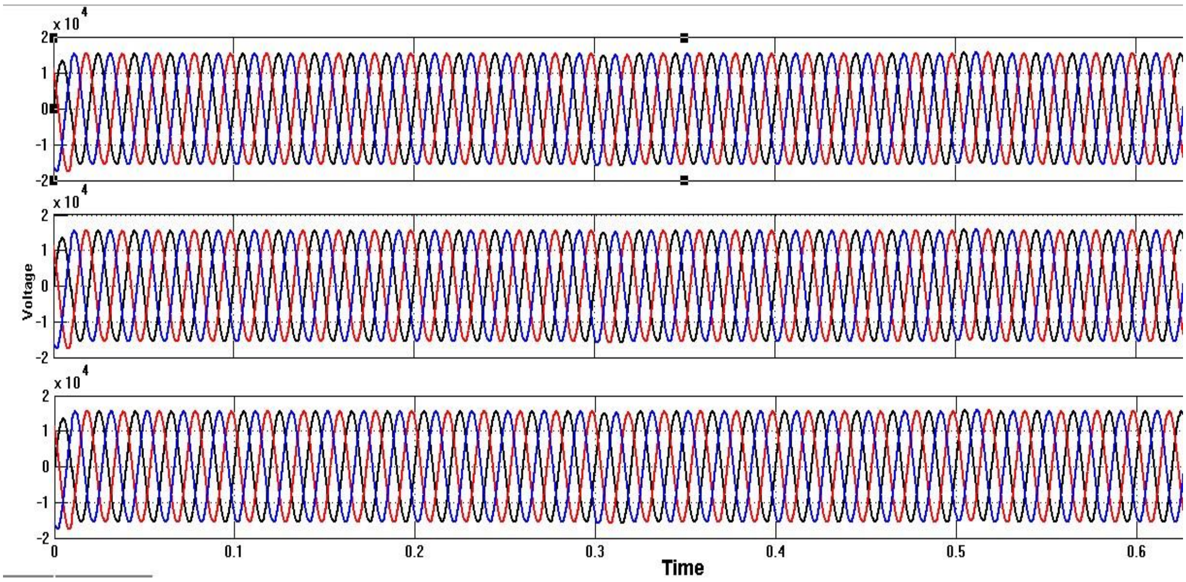

Figure 9. Voltage profile (Vabc): GWO fed DVR & BO fed DSTATCOM injected voltage, compensated voltage at load for 57 bus

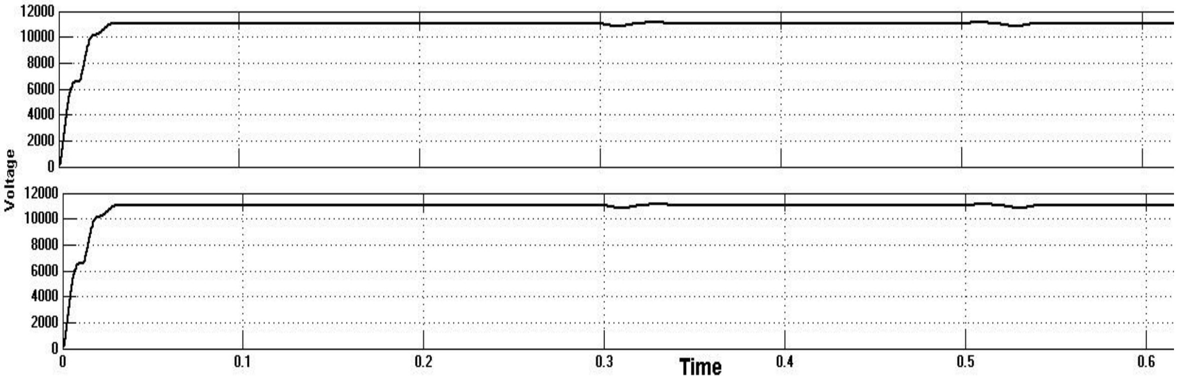

Figure 10. Voltage profile (Vrms): before & after compensation (Swell) for 57 bus

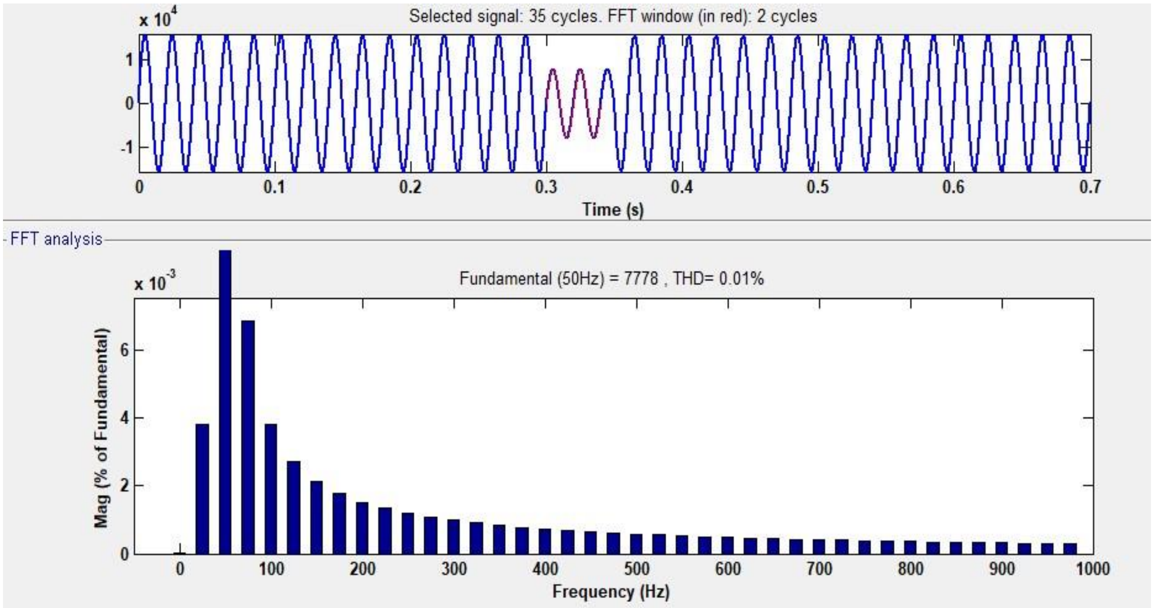

Figure 11. Total harmonic distortion of voltage Sag GWO fed DVR & BO fed DSTATCOM i,e. T.H.D = 0.11% for 57 bus

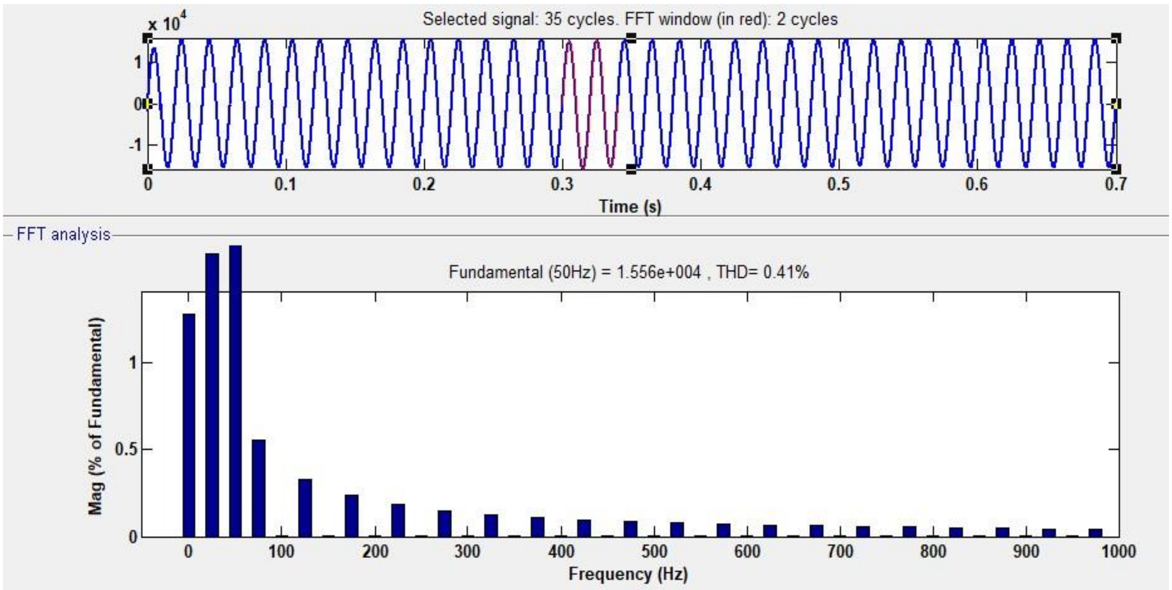

Figure 12. Total harmonic distortion of voltage swell GWO fed DVR & BO fed DSTATCOM i,e. T.H.D = 0.41% for 57 bus

Table 1. Simulation outcomes with settling time, THD, % of sag & swell for IEEE 33 & 57 bus

S. No.	Compensator	Settling time (sec.)	Peak	THD
1	DG (conventional)	0.1-0.6 (0.5sec)	1.2	12.7%
2	DG-DSTATCOM			
	Sag	0.3-0.5 (0.2sec)	0.5	5.77%
	Swell	0.3-0.5 (0.2sec)	0.5	4.34%
3	GWO-DVR & BO –DSTATCOM 33 bus			
	Sag	0.3- 0.35 (0.05sec)	0.1	0.11%
	Swell	0.3- 0.35 (0.05sec)	0.1	0.41 %
4	GWO-DVR & BO –DSTATCOM 57 bus			
	Sag	0.3- 0.35 (0.05sec)	0.1	0.41%
	Swell	0.3- 0.35 (0.05sec)	0.1	0.40%

3. CONCLUSION

The PQ issues of custom power electronic gadgets D-STATCOM, DVR have been suggested in this text, including interruptions and swells, voltage dips, repercussions, and mitigation strategies. GWO fed DVR and BO fed D-STATCOM applications and designs for swells and interruptions, voltage sags, and comprehensive outcomes are discussed. A novel PWM-based control method is executed to handle electronic valves in VSI utilized in GWO fed DVR and BO fed DSTATCOM. In contrast of principal frequency exchanging plans currently accessible in MATLAB/Simulink, this PWM control model just needs voltage estimations. The enhanced step reaction of generator terminal voltage utilizing MBO is enhanced and contrasted with various techniques suggested by different specialists. The simulation outcomes exhibit that suggested improvement strategy is very effective for tuning the PI factors. This property makes it ideal for low-voltage bespoke power applications. The calculations revealed that a GWO-fed DVR provides the optimum voltage regulating capabilities. It was also noticed that capability for voltage regulation and power compensation of BO fed DSTATCOM relies upon the DC storage gadget rating. The simulation outcomes show great precision results. Setting season of swell and sag is decreased and THD is diminished from 5.77% to 0.11 and 0.41%.

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