Performance Analysis of Grid-Connected Wind Energy during Symmetrical fault using FACTS Devices

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Abstract

In recent years, whereas integrating the wind turbine energy sources, voltage control is an important factor which has to be controlled due to the change in fault ride-through capability during voltage response. Most of power quality problems for grid connected Doubly Fed Induction Generators (DFIG) wind sources comprise flicker, voltage magnitude variations, and injected harmonics because of switching in converters. In this research, the wind farm with DFIG's is stabilized using three different FACTS devices, such as Static VAR compensator (SVC), Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controllers (UPFC). Furthermore, three lines to ground fault (LLL-G) of fault measures are analyzed in the simulation test cases utilizing MATLAB which presented a 9 MW which transferred to utility grid. So, Moth Flame Optimization with Improved Firefly Algorithm (MFO-IFFA) is proposed to inject or absorb the reactive power to stabilize the system. From the simulation results, it clearly shows that the proposed MFO-IFFA based UPFC devices achieves better results of attaining higher voltage profile of 0.9972 per unit voltage stability with a reactive power injection of 1.33 Mvar which is better than the existing SVC and STATCOM which gives 0.94 & 0.9925 per unit only.

Keywords: *Fault Analysis, Improved Firefly Algorithm, Moth Flame Optimization, Static VAR compensator, Thyristor Controlled Series Compensator, Unified Power Flow Controllers*

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1. Introduction

Power quality improvement in the grids connected to wind farms leads to consumer's needs, harm reduction of the touchy device, and development of wind strength plant life [1], [2]. Due to the inherent aerodynamic results of wind velocity inclusive of speed non-stop variations, turbulence, and gusty wind, wind farm output electricity is fluctuated and consequently the grid voltage can be varied [3]. These variations reason energy great problems, specifically flicker emission Sometimes, it's miles essential to differ grid voltage level with the aid of converting electricity aspect and consequently the use of this technique is restricted [4]. Another technique is called voltage manage and, according to this method, the reference reactive power is derived through a stator voltage manage loop with the aid of a voltage regulator [5], [6]. Voltage manipulate method is restricted due to the probability of interfering with the utility-imposed feeder voltage manipulate mechanism inclusive of On-Load Tap Changers (OLTCs). Recently, a singular voltage manipulates mixed with reactive power manipulate changed into cautioned in [7] with the aid of an algorithm to extract the reference voltage fee for the Point Of Common Coupling (PCC). The manipulate device consists of two controllers in cascade for the wind farm and turbine manipulate [8].

There are such a lot of strategies to dispose of the energy best problems of wind turbine electricity vegetation. One of the quality answers is to apply digital based FACTS devices and located very helpful for improving strength great [9], [10]. If the fault happens on the grid this is linked to the wind turbine power plant, FACTS Devices are the best technique to preserve the steadiness of big energy device network. This is because if the wind turbine generator's circuit breaker receives open for the duration of grid disturbances, it'll reclose when everyday operation is resumed because of switching manipulate of FACT device [11]. The intake of reactive strength reduces the energy element. Wind turbine induction mills calls for reactive power for magnetization [12]. For compensation of reactive power, FACTS devices are used [13], [14]. FACTS devices are used for continuous supply to the load. It supports the voltage stability all through disturbance of grid and during intermittent climate situations with a view to affect the wind turbine output. FACTS tool affords reactive strength for stabilization of voltage inside the network and improves the strength issue of the machine. The output power fluctuation that occurs at wind turbine operation may produce an imbalance among the power demand and supply [15].

The major contributions of this paper are stated as follows:

- FACTS devices are integrated with MFO-IFFA method for alleviating the power quality problem existent in the transmission line.
- The main contribution is to generate the optimum control structure for eliminating the harmonic disturbances through the identical FACTS devices.
- Proposed MFO-IFFA with FACTS devices are used for compensating the reactive power to DFGI based wind to provide optimal power.

2. Literature Review

Muhammad A. Saqib, Ali Z. Saleem [16] supplied a grid integration of wind energy assets with reactive strength repayment to improve functions of energy high-quality. Also, this research work analyses the consequence of STATCOM incorporation. STATCOM function became discovered inside the historical past of PQ issues. Furthermore, STATCOM invariably adjusts the incidence of the resonance efficiently at harmonics of whole regularities. Here and now, most of the wind energies are projected, however on the other hand it isn't some distance robust in terms of short-circuit belongings.

Sener AGALAR, Yusuf Alper KAPLAN [17] proposed a Static Transfer Switch (STS) and DVR changed into associated with WES within the route of advancing the features of power exceptional. The STS system is applied to check the oscillations that can occur inside the power because of the wind pace dissimilarities. But DVR has restricted proficiencies and could utmost potential to appearance voltage sag outdoor at the assortment of full recompense.

Miguel Ochoa-Giménez et al. [18] evolved a well-organized more than one-reference-body regulator for errors dominance in traditional strength strategies. The projected structure permits recursive control even as denoting alerts to place frames revolving synchronously thru harmonic correspondent area guidelines while a least feasible of trigonometric-characteristic calculations. But it has completely been deliberated as convoluted due to the facts that numerous trigonometric capabilities need to be intended concurrently.

Sitharthan et al. [19] proposed a hybrid GA more suitable Elman Neural Network (GA-ENN) Regulator for proton interchange gasoline cell sustained modified Dynamic Voltage Restorer (DVR) to boom the fault ride-thru functionality of DFIG structured wind electricity. The proposed GA-ENN became used to boom the capabilities of PQ at some stage in irregular occasions. But in some of the abnormal cases, it'll overcome a part of exploration area and eat overflowing electricity through a exact time period.

Om Prakash Mahela, Abdul Gafoor Shaik [20] provided PQ enhancement technique in the existence of grid instabilities and wind dissemination the use of DSTATCOM through battery connected ESS. Synchronous Reference Frame (SRF) principle-structured manipulate set of rules was exploited for the regulator of DSTATCOM and SRF model controller entails the sensing of line voltages and cargo currents. However, this technique turned into restrained to a limited blunders fee and it could present significance in this shape.

M. G. Hemeida, H. R. Hussien, M. A. Abdel Wahab [21] has offered the stabilization of a Wind Farm Using Static VAR Compensators (SVC) Based Fuzzy Logic Controller to enhance brief stability and damping strength oscillations of a wind farm linked to electricity device. Different fault sorts and extraordinary fault intervals have been taken into consideration for the observe to analyze the impact of the SVC based FLC on device stability. The proposed controller presents the wind farm device with damping effect for the duration of brief circumstance and provides a lot smoother and faster response in the publish-fault situations. But the machine without SVC couldn't aid the system i.E. The safety devices disconnect the wind farm.

3. Modeling of FACTS devices

The FACTS devices are used in the transmission network to achieve a reliable, stable and secure power system network. Hence, it is essential to identify the proper allocation and size of the FACTS devices during the device placement.

3.1 Modelling of SVC

SVC is an integration of a thyristor-controlled reactor and a thyristor switched capacitor which is illustrated in Figure 1. SVC is used to inject or absorb the reactive power for regulating the end voltage of the transmission line system. The reactive power is injected into the system when the load is highly inductive. Similarly, the reactive power is absorbed by the SVC, when the system has a higher reactive power flow. The reactive power range is limited as follows: -100 MVAR $\leq Q_{svc} \leq$ 100 MVAR.

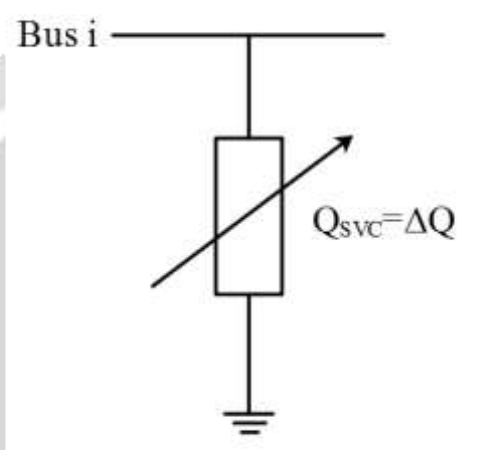

Fig. 1 Model of SVC in transmission line

The location of the SVC in a node is expressed in the following equation (1).

$$\Delta Q = Q_{SVC} \tag{1}$$

where the size of SVC is represented as ΔQ . The Reactive Power Dispatch (RPD) issue with SVC placement is given in the following section:

3.2 Modeling of TCSC

The capacitive or inductive reactance is included by the TCSC for modifying the effective series reactance of the transmission line. The TCSC placement in the network is used for continuous power control in the transmission line network. In the power system network, the TCSC controls the power flow and can eliminate the sub-synchronous resonance. Moreover, the TCSC improves the transient stability and damp outs the inter-area power oscillations. The TCSC model in a transmission line is illustrated in Figure 2.

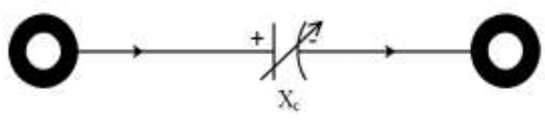

Fig. 2 Model of TCSC in transmission line

The location of the TCSC in a node is expressed in the following equation (2).

$$X_{TCSC} = r_{TCSC}.X_{Line} \tag{2}$$

where the transmission line reactance is specified as X_{Line} and r_{TCSC} represents the coefficient that specifies the degree of composition by TCSC. The operating range of the TCSC is selected between -0.8 X_{Line} and 0.2 X_{Line} for avoiding overcompensation. The ideal position of the reactance is obtained by minimizing the reactance among the specified ranges. Additionally, the variable capacitance of the TCSC is adjusted based on the load requirement.

3.3 Modelling of UPFC

The modeling of UPFC is the combination of TCSC and SVC coupled with the bus. Hence, the power flow in UPFC occurs based on the line reactance, phase angle, and bus voltage. The schematic representation of the UPFC is given in the following Figure 3 and equation (3) expresses the power flow of the UPFC. -

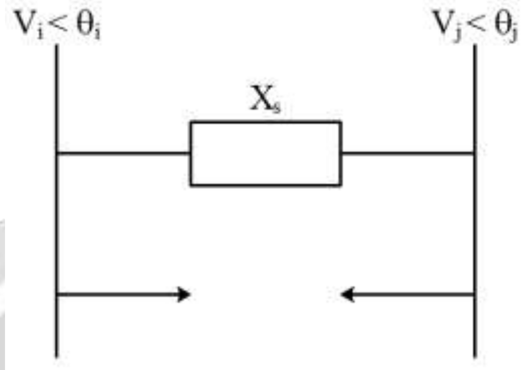

Fig. 3 Schematic representation of the UPFC

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin(\delta_i - \delta_j) \tag{3}$$

If the UPFC is located between the node i and j, the admittance matrix adjusts the reactance. The reactance is equal to the X_s between two nodes and appropriate power, insertion leads to change in the jacobian matrix.

4. Proposed Method

4.1 Moth Flame Optimization

MFO is generally a population-based metaheuristic algorithm which is developed by the Mirjalili. At first, MFO randomly creates the moths inside the solution space and fitness values are generated for each moth. Next, an optimal location is tagged by the flame. The function of spiral movement is used to define the location update of the moths. This location update is used to obtain the optimal location labeled by the flame and a new best individual location is updated in the MFO. The same processes such as location update of the moth and new location generation are performed in the MFO.

The processes carried out by the MFO algorithm is mentioned as follows:

a. Initial location generation of the moth

Equation (4) is the set of moths generated by the MFO algorithm.

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & m_{1,d} \\ m_{2,1} & m_{2,2} & \cdots & m_{2,d} \\ \vdots & \vdots & \vdots & \vdots \\ m_{n,1} & m_{n,2} & \cdots & m_{n,d} \end{bmatrix} \tag{4}$$

Where, the amount of moths is represented as n and the dimension of the solution space is represented as d. The moth's fitness values are stored in an array manner as shown in the equation (5).

$$OM = \begin{bmatrix} OM_1 \\ OM_2 \\ \vdots \\ OM_n \end{bmatrix} \tag{5}$$

The other fundamental of the MFO is flame which is expressed in the equation (6) and the fitness function for the flame is expressed in the equation (7).

$$F = \begin{bmatrix} F_{1,1} & F_{1,2} & \dots & F_{1,d} \\ F_{2,1} & F_{2,2} & \dots & F_{2,d} \\ \vdots & \vdots & \vdots & \vdots \\ F_{n,1} & F_{n,2} & \dots & F_{n,d} \end{bmatrix} \tag{6}$$

$$OF = \begin{bmatrix} OF_1 \\ OF_2 \\ \vdots \\ OF_n \end{bmatrix} \tag{7}$$

It is well-known that both the moths and flames are the solutions. The dissimilarity among the moths and flames are the way of treating and updating them in each iteration. Some definite search agents in the search space is the moths and optimal location of the moth is given in the flame.

b. Location update of the moth

Three different functions are considered in the MFO for converging the global optimal of the optimization issues. Equation (8) is used to define the function used in the converging purpose.

$$MFO = (I, P.T) \tag{8}$$

Where, the moth's initial random position is represented as I; the moth's movement in the search space is P and search process completion is denoted by the T. The random dissemination of the moths are denoted in the equation (9).

$$M(i,j) = (ub(i) - lb(j)) \times rand() + lb(i) \tag{9}$$

Where, the ub and lb denotes the upper bound and lower bound of the variables respectively. Here, the moths are flied in the search space based on the transverse direction. Equation (10) shows the logarithmic spiral of the MFO.

$$S(M_i, F_j) = D_i . e^{bt} . \cos(2\pi t) + F_j \tag{10}$$

Where, the distance among the moth i and flame j is denoted as D_i; the fix to refer the form of logarithmic spiral is represented as b and the random number created in the range of $[-1,1]$ is represented as t. The spiral movement of moth close to the flame is used to balance the exploration and exploitation features.

c. Updating the amount of flame

This phase is used to improve the exploitation of the MFO in which location of the moth is updated at the n locations of the search space. This leads to reduce the probability of exploitation of optimal solutions. Hence, it is solved by reducing the amount of flames as shown in the equation (11).

$$flame\ no = round\left(N - l \times \frac{N-l}{T}\right) \tag{11}$$

Where, the amount of flames is represented as N; current iteration number is l and a maximum iteration number of T.

4.2 Improved Firefly Algorithm

By investigating the boundaries of the FA, light retention coefficient γ is excessively enormous and works as decent worth. Every firefly contains bright influence $I\ (r)$ which is written as

$$I\ (r) = I_0 e^{-\gamma r^m}\ m \geq 1 \tag{12}$$

So, firefly attraction β can be diverges conferring to the calculation assumed through (13),

$$\beta(r) = \beta_0 e^{-\gamma r^m}\ m \geq 1 \tag{13}$$

where β_0 signifies the greatest engaging quality (at r = 0) and γ is the light assimilation constant, that regulates the diminishing of the light power. The expanse amongst dual fireflies i and j at p_i and p_j locations are considered as

$$r_{ij} = |p_i - p_j| = \sqrt{\sum_{k=1}^{l} p_{i,k} - p_{j,k}{}^2} \tag{14}$$

where $p_{i,k}$ is three-dimensional harmonize p_i. The effort is defined by

$$p_i = p_i + \beta_0 e^{-\gamma_{ij}{}^2}\left(p_i - p_j\right) + \alpha(rand\,\tfrac{1}{2}) \tag{15}$$

where the initial term is the current situation of a firefly I (p_i is the arrangement of a firefly). At every iterative advance, the splendor and the engaging quality of every firefly is registered. The brilliance of every firefly is contrasted and any remaining fireflies and the places of the fireflies are refreshed utilizing condition (15).

5. Result and Discussion

The simulation of this entire system is performed using the MATLAB/SIMULINK R2018a. In this proposed system, MFO-IFFA based FACTS model is used for injecting/absorbing the reactive power to maintain the stable power quality in the wind turbine. The overall Simulink model of the proposed method is given in Figure.4. The specifications of generator, turbine are given in Table 1.

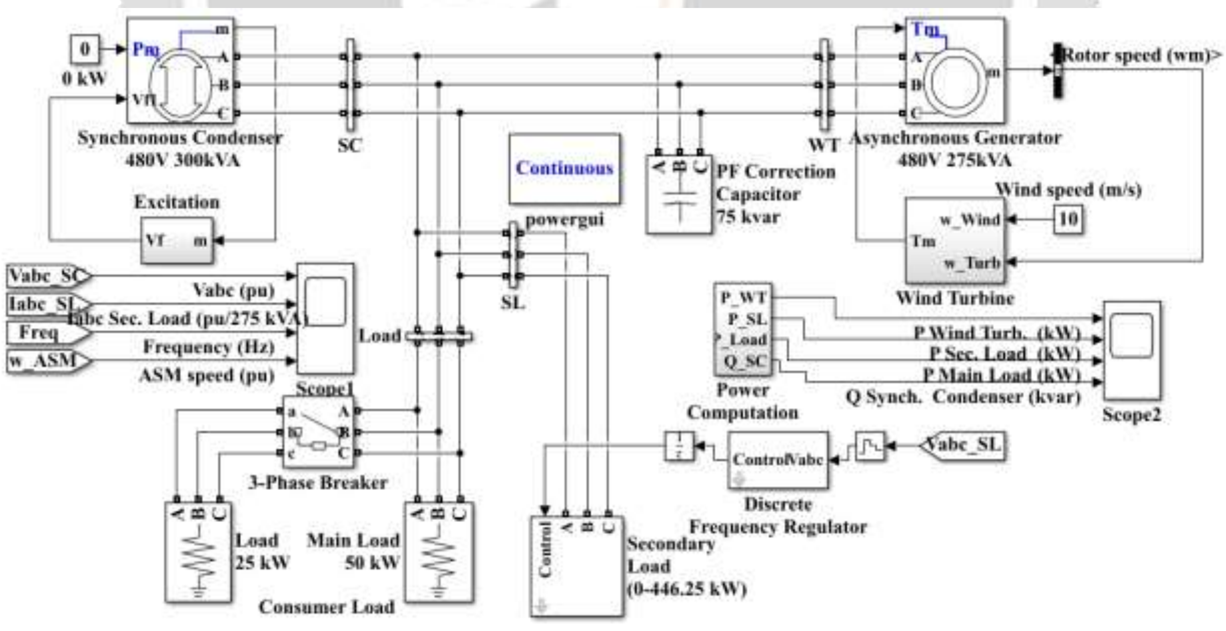

Figure.4. Simulink model for STATCOM with wind turbine induction generator

Table.1. Specifications of DFIG Generator

Friction factor	0.01

Nominal frequency (Hz)	50
Rotor (pu)	0.004377
Initial conditions [deg]	-0.01
Wind speed (m/s)	9
Stator (pu)	0.004843
Rotational speed (pu)	1
Pitch angle (deg/s)	2
Output power (W)	2*1.5e6
Maximum pitch angle (deg)	45
Magnetizing inductance (pu)	6.77
Gain: [Kp Ki]	5,25

The fault period effect and fault duration balance of wind farm are connected to the grid is analyzed through this proposed machine underneath various fault. The fault vicinity effect over the behavior of the wind farm is analyzed beneath different fault sorts whilst the proposed machine has FACTS and without FACTS. In this proposed device, anybody of the faults is created inside the wind turbine induction generator at distinct version of time for extraordinary sorts of faults.

5.1 Performance of SVC under three phase Fault condition

Figure 5, 6 and 7 shows the performance of SVC under three phase fault conditions. During fault period, the real and reactive power of the wind is decreased from 9 to 6 MW and 4.5 to 3 Mvar respectively.

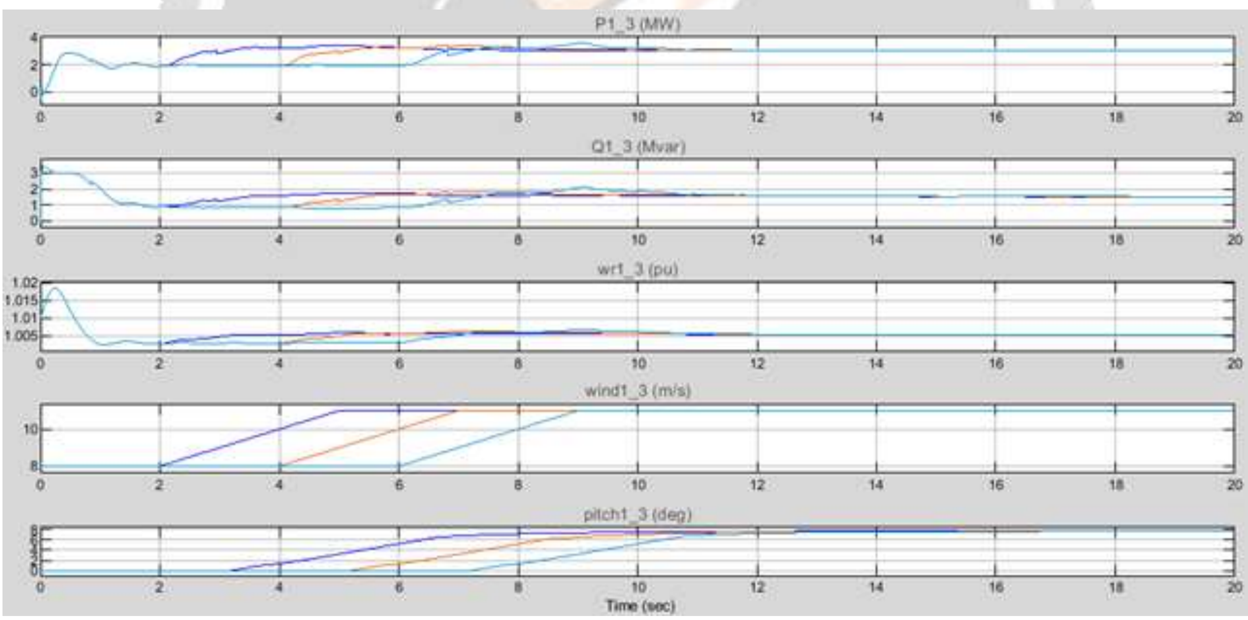

Figure.5. Performance of wind turbine

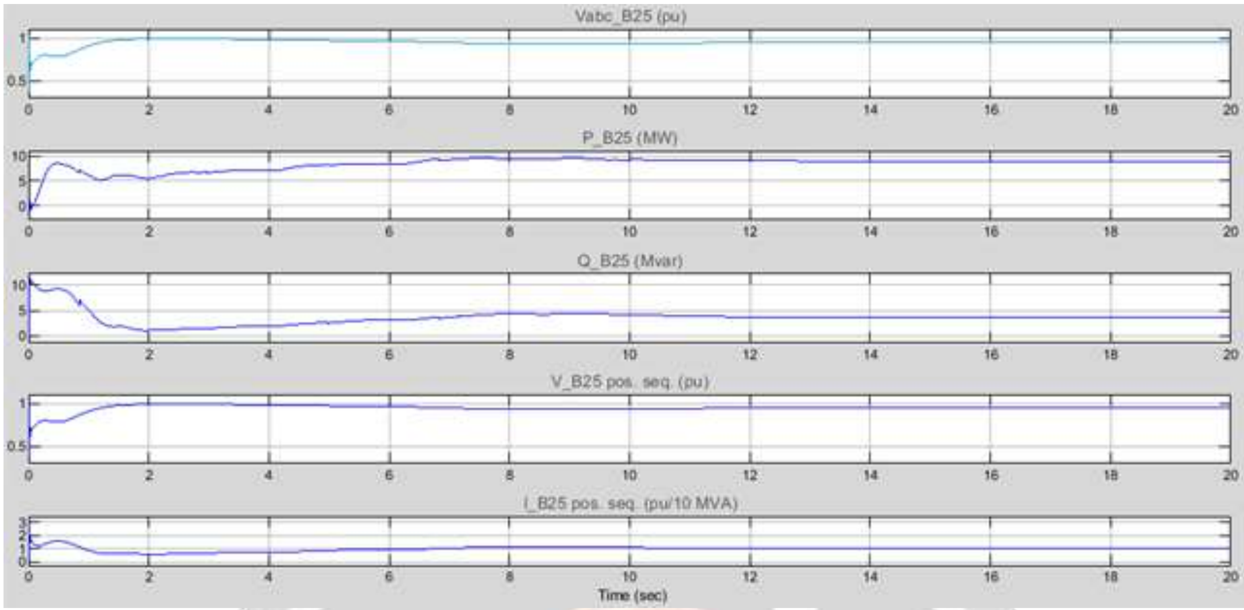

Figure.6. Performance at bus B25

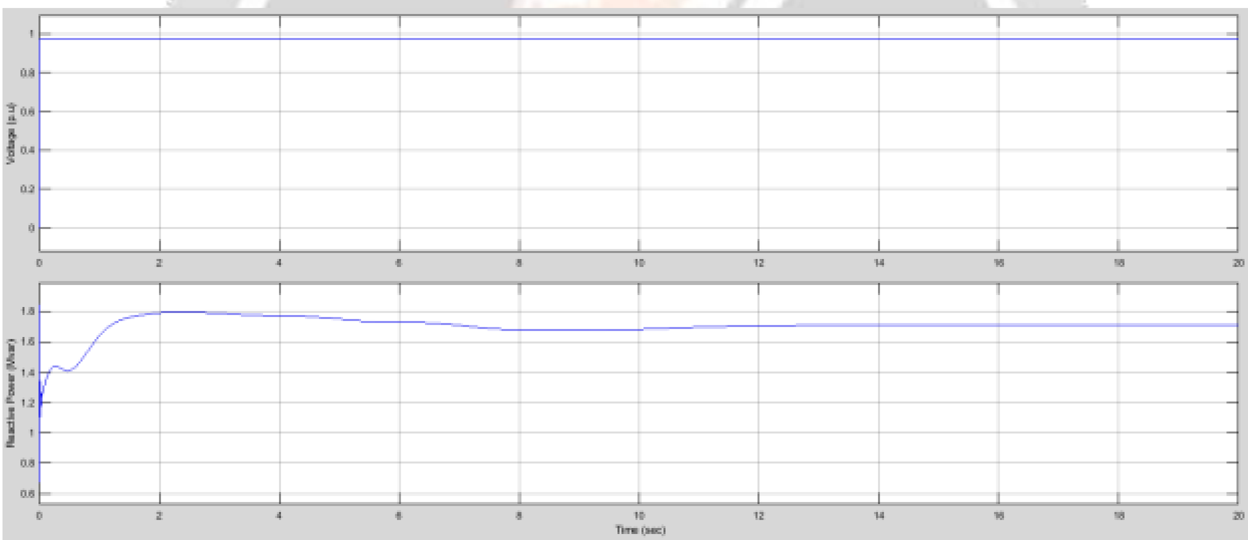

Figure.7. Performance of SVC

Once the fault is happened, the pitch angle is reduced to 6 deg. Finally, the pitch angle is going to 0 deg after 17 sec. The voltage of the B25 is increased from 0.9 to 1 Pu. The real and reactive power of the B25 is decreased from 9 to 6 MW and 4 to 2 Mvar respectively. From the figure 10, it clearly indicates that proposed MFO-IFFA based SVC achieves the voltage magnitude of 0.9744 per unit with reactive power injection of 1.74 Mvar.

5.2 Performance of TCSC under three phase Fault condition

Figure 8 and 9 shows the performance of the wind turbine and B25 respectively when the system has TCSC during the LLL-G fault. Where figure 10 shows the reactive power injection of TCSC.

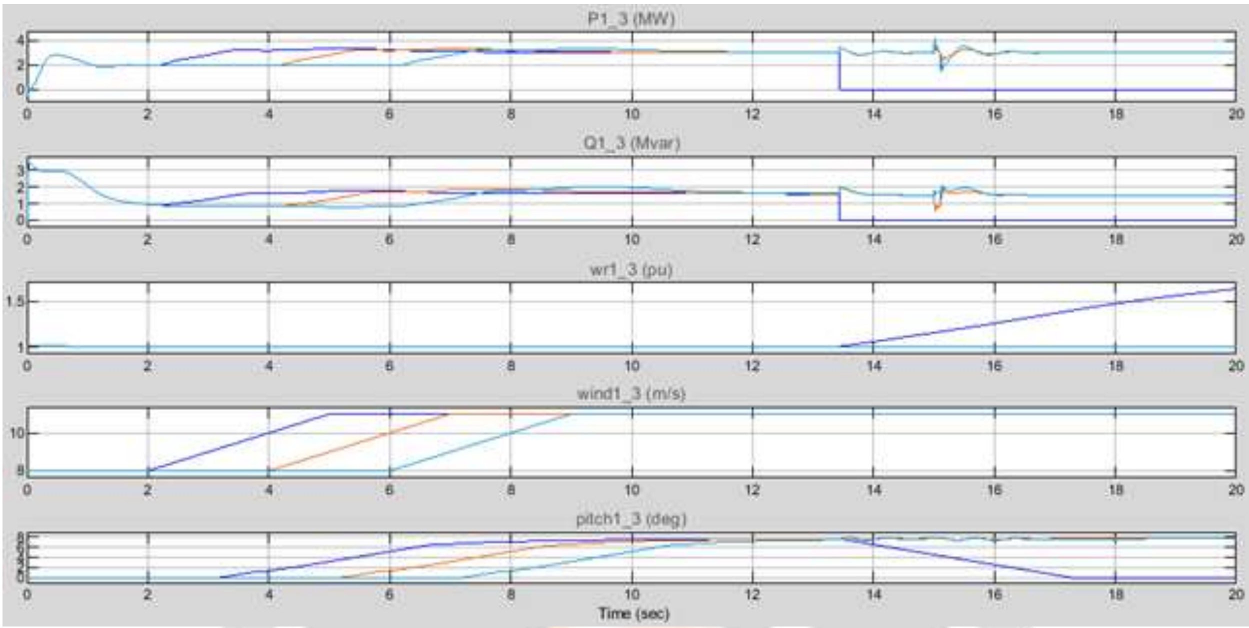

Figure.8. Performance of wind turbine

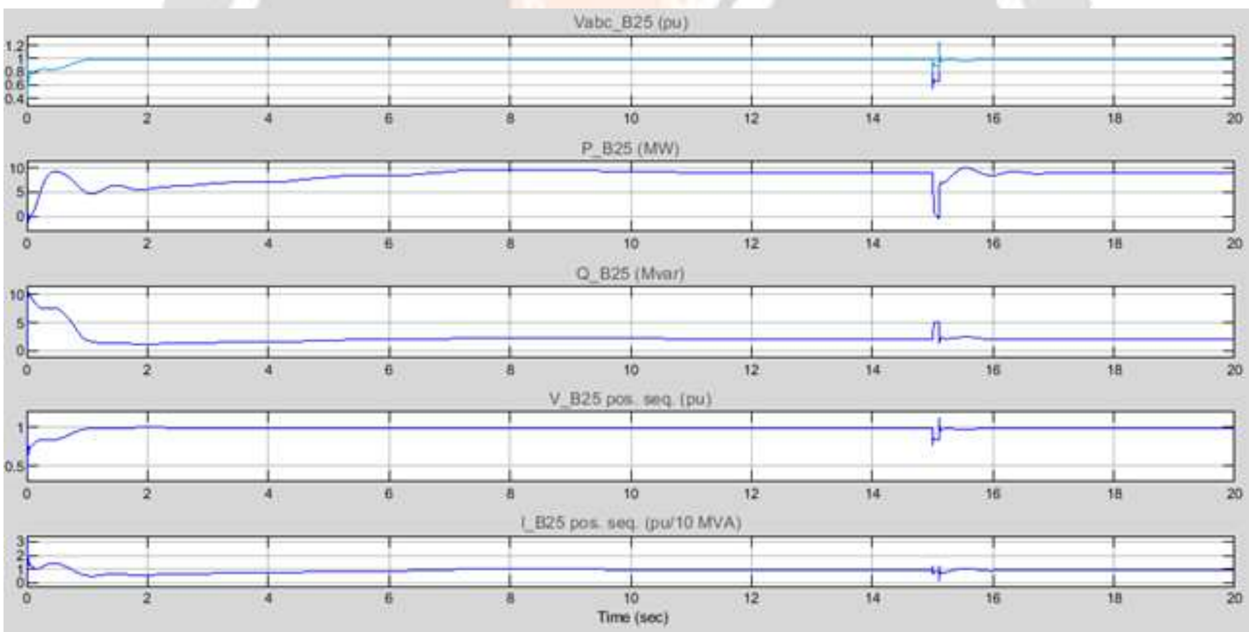

Figure.9. Performance at bus B25

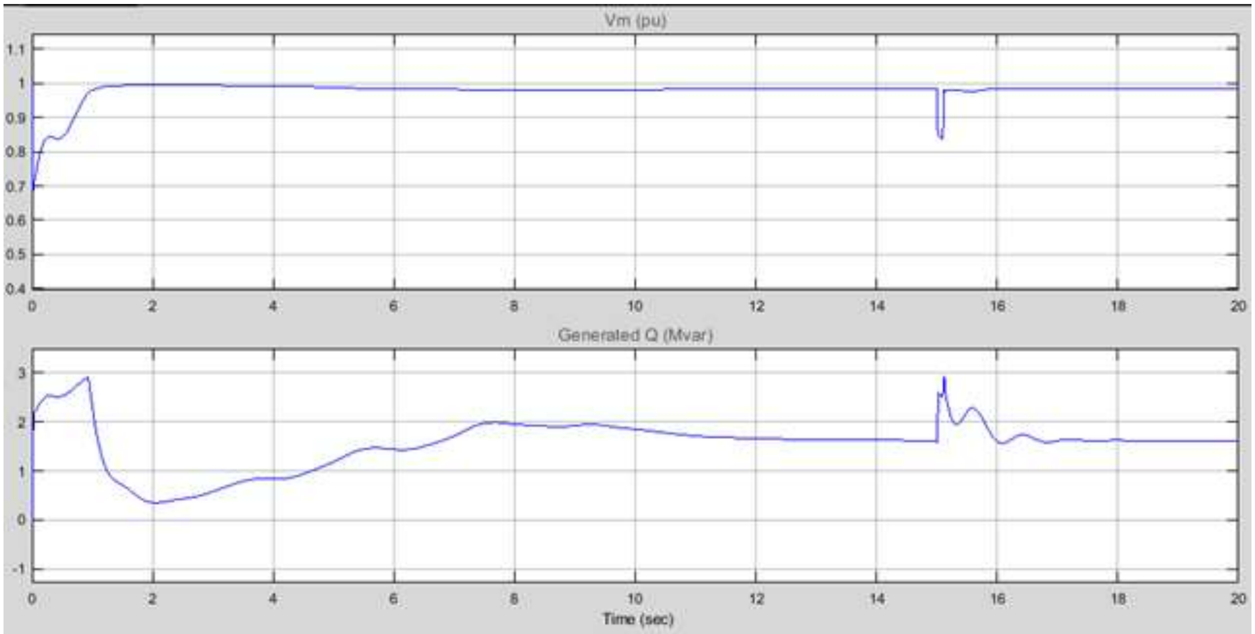

Figure.10. Performance of TCSC

When the system runs from 13.41 to 15.11s interval, the reactive power and pitch angle is increased from 4.3 to 4.5Mvar and 7 to 8deg respectively. The voltage of B25 and real power are stabilized 0.94Pu and 9MW and 2Pu respectively. The reactive power is 4.6Mvar at 13.41 and 4.5Mvar at 15.01 and 15.11s. From the figure 10, it clearly indicates that proposed MFO-IFFA based TCSC achieves the voltage magnitude of 0.9813 per unit with reactive power injection of 1.68 Mvar.

5.3 Performance of UPFC under three phase Fault condition

Figure 11 and 12 shows the performance of the wind turbine and B25 respectively when the system has UPFC during the LLL-G fault. Where figure 13 shows the reactive power injection of UPFC.

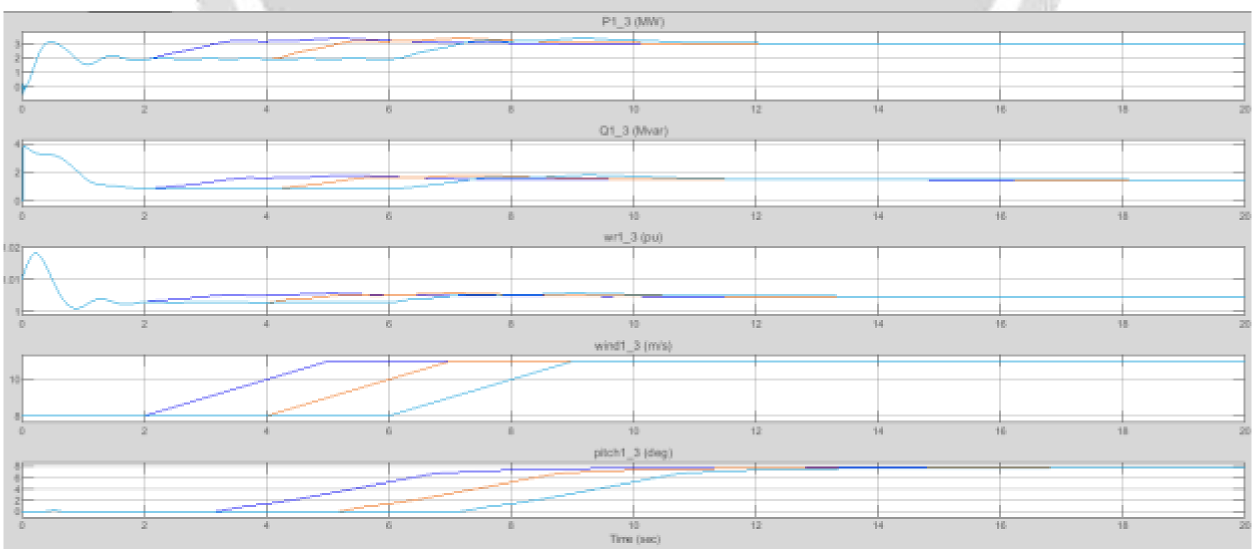

Figure.11. Performance of wind turbine

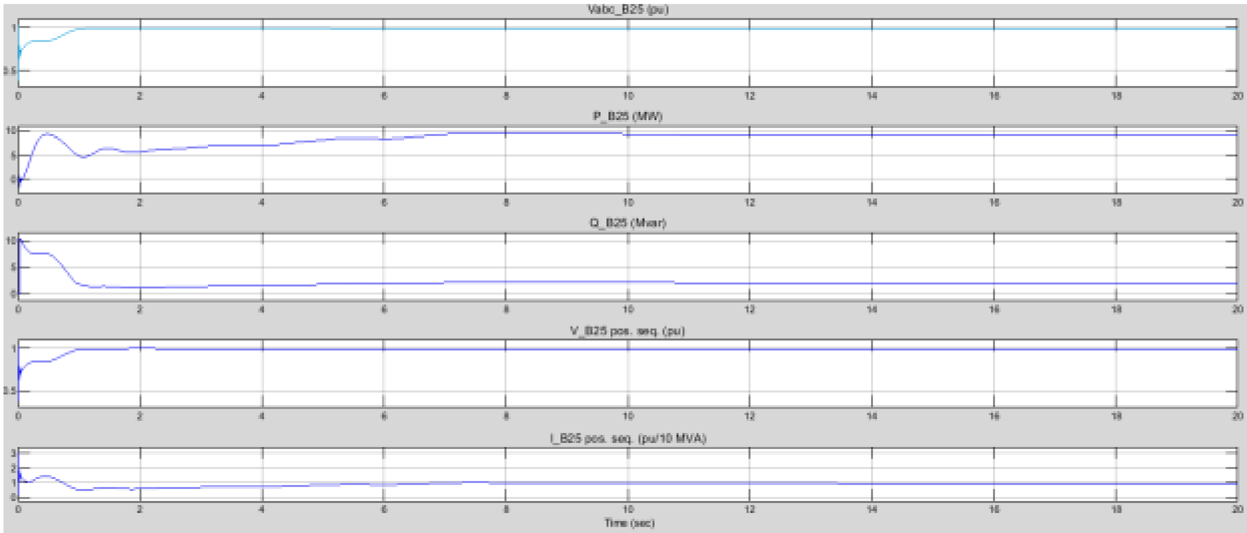

Figure.12. Performance at bus B25

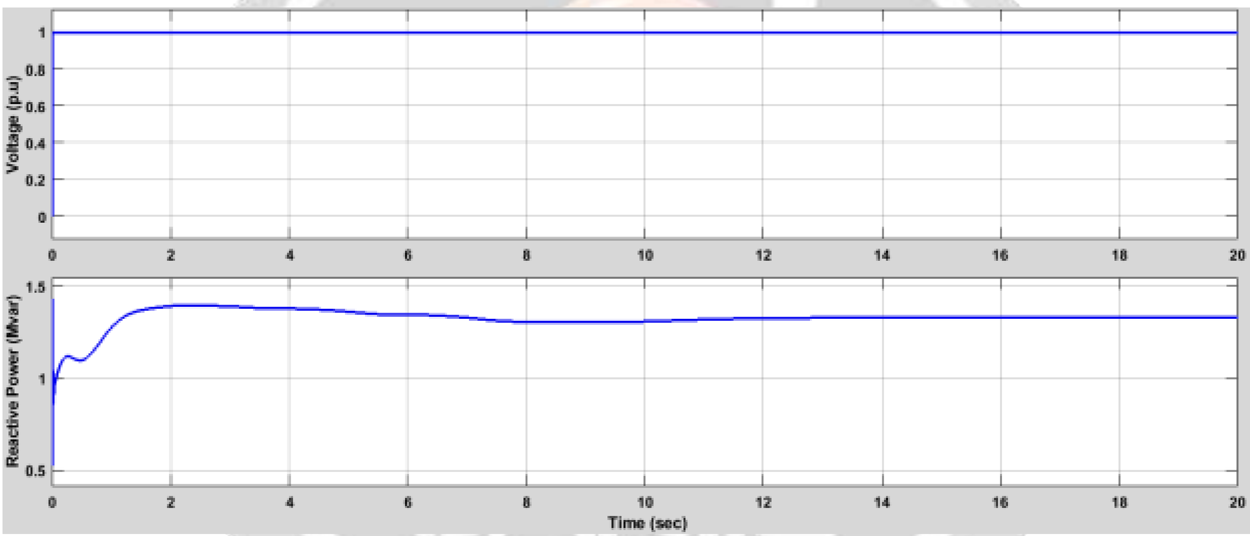

Figure.13. Performance of UPFC

The fault location of LLL-G fault in the wind turbine is 15.11s. The real power of the wind is 9MW and it is decreased to 0.5MW at the first fault of 15.1 sec. Furthermore, this real power is decreased into 0MW in 15.11s. The reactive power of the wind turbine is decreased 2 and 1Mvar at 15.1 and 15.11s respectively. Then this reactive power goes to 0. The pitch angle is going 8, 7, 6.8 deg when the wind farm run at 14, 15.1 and 15.11s respectively. Normally, the voltage of the B25 is 1Pu stable from 11 to 14s. In first fault, the B25 voltage is decreased from 1 to 0.4Pu at 15.1s and in second fault it is increased from 0.4 to 1.3 t 15.11s. From the figure 13, it clearly indicates that proposed MFO-IFFA based UPFC achieves the voltage magnitude of 0.9972 per unit with reactive power injection of 1.33 Mvar.

5.4 Comparative analysis

The presentation of proposed MFO-IFFA with UPFC is analyzed with existing SVC and STATCOM. For comparison, the wind farm with three-line ground fault (LLL-G) of UPFC is taken with SVC, STATCOM under LLL-G. Table 3 tabulates the comparative analysis of FACTS controller. From the table 3, it clearly shows that the proposed MFO-IFFA achieves the maximum voltage magnitude of 0.9972 p.u. with reactive power injection of 1.47 Mvar. While the existing Fuzzy Logic based SVC [21] and STATCOM achieves the voltage magnitude of 0.94 &

0.9925 by injecting higher reactive power of 1.85 & 1.65 Mvar which is high when compared to proposed UPFC devices.

Table 2. Comparative Analysis of FACTS devices

Parameters	FLC based SVC [21]	Existing STATCOM	Proposed MFO-IFFA based UPFC
Reactive Power (Mvar)	1.85	1.65	1.33
Voltage Magnitude (per unit)	0.94	0.9925	0.9972

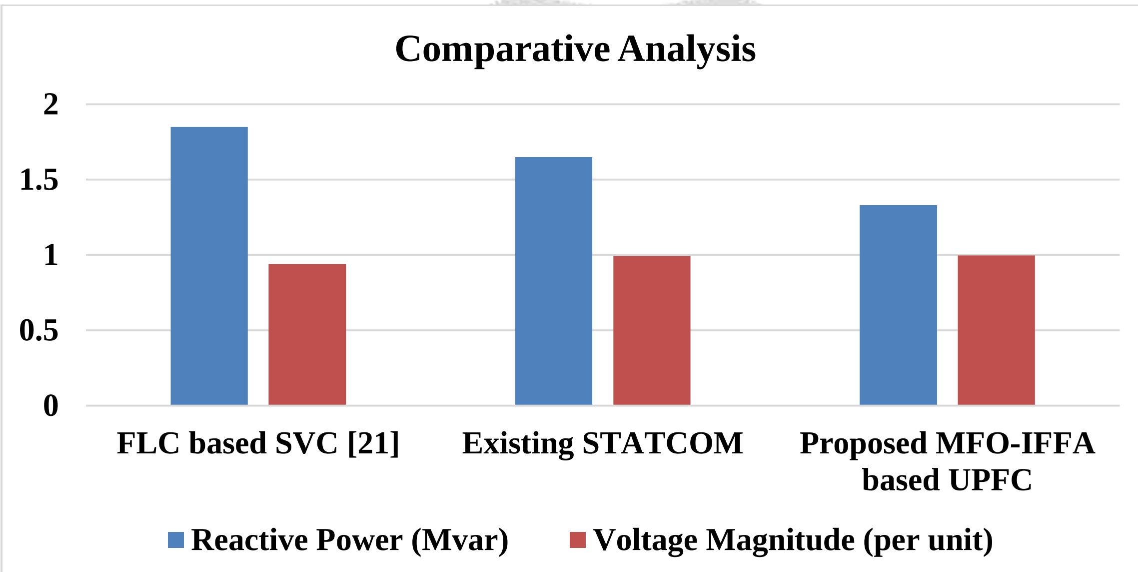

Figure 14. Comparative Analysis of FACTS devices

Figure 14 illustrates the comparative analysis of FACTS devices. From the figure 14, it clearly shows that the proposed MFO-IFFA based UPFC devices achieves better voltage profile and reactive power injection when compared with Existing STATCOM and FLC based SVC devices.

6. Conclusion

This research work has mainly focused on numerous challenges in grid coupled nonlinear wind turbine while connecting the FACTS devices. The conventional techniques are used for injecting the reactive power and voltage magnitude when the fault is created in the transmission line. The equivalent model is shunt connected with the terminal that is the wind turbine system is connected for supplying the required reactive power during the grid faults. On the other hand, to improve the effectiveness of DFIG power, a novel control strategy name called MFO-IFFA is developed. This paper is very helpful to find the modelling of DFIG based Wind Turbine in current trends and the next level of problem identification. The proposed MFO-IFFA based FACTS model is connected with the wind system for supplying the required reactive power during the grid faults. The simulation results, clearly show the wind farm with proposed MFO-IFFA model gives 0.9972 per unit voltage stability with a reactive power injection of 1.33Mvar which is better than the existing STATCOM which gives 0.9925 per unit only with reactive power injection of 1.65 Mvar. In future, this research has been extended through the Wind turbine system which will be analyzed with Permanent Magnet Synchronous Generator by integrating various FACTS devices

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