21th International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24th to 26th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

Implementation of Grid-Connected Wind Energy during Fault Analysis Using Moth Flame Optimization with Firebug Swarm Optimization

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Abstract: In modern trends, the voltage profile has become increasingly critical when incorporating wind turbine energy sources because of changes in fault ride-through capabilities throughout voltage reaction. Ripple, voltage magnitude changes, and injected harmonics due to conversion switches are power quality issues for grid-integrated doubly fed induction generators (DFIG) wind sources.

In this study, FACTS (flexible alternating current transmission system) devices like the static VAR compensator (SVC), thyristor controlled series compensator (TCSC), unified power flow controllers (UPFC), and static synchronous compensators (STATCOM) are used to stabilise wind energy with DFIGs. The simulation test cases using MATLAB also analyse three lines to ground fault (LLL-G) of fault measures, which showed a 9 MW that transferred to utility grid. Therefore, it is suggested to inject or absorb reactive power to stabilise the system using moth flame optimization with firebug swarm optimization (MFO-FSO). The simulation results clearly demonstrate that the proposed MFO-FSO based STATCOM devices outperform the current non-linear generalized predictive control based STATCOM, which only achieves 0.9815 per unit voltage stability, by achieving a higher voltage profile of 0.9925 per unit voltage stability with a reactive power injection of 1.82 MVAR.

Keywords: Doubly Fed Induction Generators, FACTS devices, Firebug Swarm Optimization, Moth Flame Optimization, Wind Energy.

1. Introduction

For the past few years, improved power quality in grids connected to wind farms supports consumer demands, the protection of delicate equipment, and the growth of wind energy plant life [1], [2]. The inherent aerodynamic effects of wind velocity, which include speed changes that occur continuously, turbulence, and gusty wind, cause fluctuations in wind farm output power [3]. Grid voltage can be changed as a result. These variations, particularly flicker emission, bring on significant energy problems. The application of this technology is constrained [4] because it occasionally becomes required to change grid voltage levels via converting electrical aspect. Another technique known as voltage management produces the reference reactive power over a stator voltage control circle [5], [6]. The voltage manipulate strategy (OLTCs) is restricted since there is a chance of interacting with both the utility-imposed feeder voltage control mechanism, which includes on-load tap changers [7]. Additionally, a current warning was issued in [8] on a method of extracting the reference voltage charge for the point of common coupling using a single voltage control combined with reactive power manipulation (PCC) [9]. The wind farm and generator are controlled by the manipulator device, which consists of two actuators [10].

The energy issues presented by the use of wind turbines to generate electricity can be solved in a variety of ways. Utilizing digital-based FACTS devices, that have been proved to be quite helpful in terms of improved quality [11], [12], is one of the finest choices. If a fault develops on the grid that is connected to a wind turbine power plant, FACTS Devices are the best solution to ensure the stability of a big energy device network [13]. That's because the switching operation of the FACT device would enable the circuit breaker on the wind turbine generator to reclose if it is left open for the duration of grid disturbances [14].

As reactive power is used up, the energy element decreases. Reactive power is required for the induction mill magnetization of wind turbines [15], [16]. Reactive power is compensated for using FACTS devices [17], [18]. FACTS devices are used to deliver the load continuously. To affect the output of wind turbines, it ensures voltage stability amid grid disturbances and sporadic weather conditions. The FACTS tool improves the machine's strength problem and delivers reactive power for network voltage regulation [19]. An imbalance between the supply and demand for power may result from the output power variation that occurs during wind turbine performance [20].

2. Literature Review

Using a contemporary UPFC, T.A. Sivakumar and M. Mary Linda [21] have shown the dynamic performance of grid-connected wind farms. Using HVDC and STATCOM centered on a non-linear controller, M. Darabiana et al. [22] suggested a Non-linear Generalized Predictive Control (NGPC) for the stability study in a hybrid power system consisting of series and parallel compensators in the presence of wind farms. The improvement of steady-state and transient operation has been proved by Reza Hemmati, Hossein Faraji, and Narges Yavari Beigvand [23] using a DFIG wind turbine coupled with an energy storage system and FACTS devices. Estimation of wind farm reactive power quick changes using an adaptive one-dimensional convolutional neural network has been proposed by Haidar Samet et al [24]. A Novel Hybrid Method for Multi-Objective Reactive Power Planning through FACTS Devices and Renewable Wind Resources has been demonstrated by Rahmad Syah et al [25].

3. Problem Statement

- To meet grid interconnection requirements and maintain the stability of the electric system, wind turbines are necessary.
- Generators supply a significant amount of power; these producers would continue to be connected to the network that encounters a serious issue during a significant increase in power.
- Voltage instability may be a concern when a failure prevents the grid-side converter from delivering the proper voltage magnitude due to power injection.
- The wind system initiates a significant amount of reactive power during the transient phase, which causes voltage instability in the system.

A. Solution

FACTS model built by a decoupled controller (MFO-FSO) is used to execute an aggregated 9 MW DFIG wind structure and monitor stability. FACTS also offers a greater level of involvement in temporary situations. The temporary outcome of the system with the MFO-FSO is executed, and the transient model is repeated. FACTS are confirmed, and additional beneficial effects of MFO-FSO on system stability are considered.

4. Proposed Method

A. Moth Flame Optimization

Moths approach nearby light sources in a winding pattern in an effort to build stable points with them. MFO follows the identical steps for updating its location and creating new locations as the moth.

Initially, equation (1) expression for the moth position is constructed using a subsequent function.

$$M_i = S(M_i, F_j) \quad (1)$$

If M_i symbolizes the i^{th} Moth, j^{th} flame is nominated through F_j and S is stated as spiral path. The route of moth is labelled in equation (2),

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

D_i is stated as distance between the i^{th} moth and j^{th} flame. b is stated as constant; t refers to time limit of [-1,1]. D_i is calculated using equation (3).

$$D_i = |F_j - M_i| \quad (3)$$

In equation (3), M_i signifies i^{th} Moth, F_j signifies j^{th} flame and D_i indicates nodes distance. Those formulations are mentioned in equation (4).

$$Flame\ no = round\ \left(N - 1 * \frac{N-1}{T}\right) \quad (4)$$

Maximum flame number is stated as N; iterations with maximum number is stated as T.

Results from MFO indicate that it can successfully handle a particular class of global streamlining problem. MFO, for instance, was successfully applied to a plan-related problem in global development. When the moth boundaries are predetermined, it can lead to early convergence and the inability to merge boundary sets. Future upgrades to the conventional MFO should achieve more advanced execution, therefore Firebug Swarm Optimization is used in conjunction with MFO to boost performance.

B. Firebug Swarm Optimization (FSO)

This study describes the organic motivation for the FSO method. The FSO algorithm starts with $NM\ and\ NF$ male and female bugs arbitrarily scattered in the solution space because every male bug consumes collection of NF female bugs. Let $\boldsymbol{m}(m).\boldsymbol{F}$ be the D by NF matrix, whose sections correlate to female bug places, is denoted by F. The problem formulation update equations (5) and (6) are presented.

$$M_x \leftarrow repmat(\boldsymbol{m}(m).\boldsymbol{x}, \boldsymbol{1}, \boldsymbol{N_F}) \quad (5)$$
$$M_y \leftarrow repmat(\boldsymbol{m}(a).\boldsymbol{x}, \boldsymbol{1}, \boldsymbol{N_F}), \quad (6)$$

where a is random number among 1 and NF. The repmat (A, m, n) proceeds a medium that comprises m duplicates of A laterally the row measurement and n duplicates laterally the column measurement. Thus if A is a p by q indexes at that time repmat (A, m, n) returns a mp by nq matrix that is formulated in equation (7).

$$\boldsymbol{m}(m).\boldsymbol{F} \leftarrow \boldsymbol{m}(m).\boldsymbol{F} + C_1 \odot (M_x - \boldsymbol{m}(m).\boldsymbol{F}) + C_2 \odot \left(M_y - \boldsymbol{m}(m).\boldsymbol{F} \right) \quad (7)$$

Since this numbers in $\boldsymbol{C_1}$ are chosen to be much bigger than $\boldsymbol{C_2}$, the above update sends each female bug. When $\boldsymbol{C_2}$ was kept shorter than $\boldsymbol{C_1}$, the FSO algorithm performed much better. The subsequent equation (8) shows the conceptual update rule for male bugs moving towards the strongest female bug:

$$\boldsymbol{m}(m).\boldsymbol{x} \leftarrow \boldsymbol{m}(m).\boldsymbol{x} + C_3 \odot (\mathrm{g} - \boldsymbol{m}(m).\boldsymbol{x}) \quad (8)$$

Even as concept of herd cohesiveness, Eq. (9) is suggested. In this aspect, the FSO differs significantly from methods such as the PSO, in which all particles strive for an unique global optimal solution.

$$\boldsymbol{m}(m).\boldsymbol{x} \leftarrow \boldsymbol{m}(m).\boldsymbol{x} + C_4 \odot (\,\mathrm{g} - \boldsymbol{m}(b).\boldsymbol{x}\,) \qquad (9)$$

This investigation for the finest reproductive mates are potential solutions. The vector x is articulated in terms of x^1 and x^2 via triangular law of vector calculation which is mentioned in Equation (10).

$$x = x^1 + a(x^2 - x^1\,) = (1-a)x^1 + ax^2 \qquad (10)$$

From the above points, it evident that the migration of male bug through location $\boldsymbol{m}(m).\boldsymbol{x}$) to appropriate female bug which is attained through (11).

$$\boldsymbol{m}(m).\boldsymbol{x} \leftarrow \boldsymbol{m}(m).\boldsymbol{x} + \boldsymbol{a}(\boldsymbol{g} - \boldsymbol{m}(m).\boldsymbol{x}) \qquad (11)$$

Furthermore, (11) is simple and relatively cheap which resulting in the update equation given Equation (12).

$$\boldsymbol{m}(m).\boldsymbol{x} \leftarrow \boldsymbol{m}(m).\boldsymbol{x} + C_4 \odot (\,\mathbf{g} - \boldsymbol{m}(b).\boldsymbol{x}\,) \qquad (12)$$

Likewise, (13) is used to explain the weak motion of female bugs towards a different male insect:

$$\boldsymbol{m}(m).\boldsymbol{F} \leftarrow \boldsymbol{m}(m).\boldsymbol{F} + C_1 \odot (\,M_x - \boldsymbol{m}(m).\boldsymbol{F}\,) + C_2 \odot \big(\,M_y - \boldsymbol{m}(m).\boldsymbol{F}\,\big) \qquad (13)$$

The two terms, $\boldsymbol{C_1} \odot (\,M_x - \boldsymbol{m}(m).\boldsymbol{F}\,)$ and $\boldsymbol{C_2} \odot \big(\,M_y - \boldsymbol{m}(m).\boldsymbol{F}\,\big)$, characterize the movement in the direction of dominant male bug and random male bug correspondingly. This method aids in the selection of the best answer while keeping the diversity of possible answers. Fig. 1 depicts the flowchart for the proposed method.

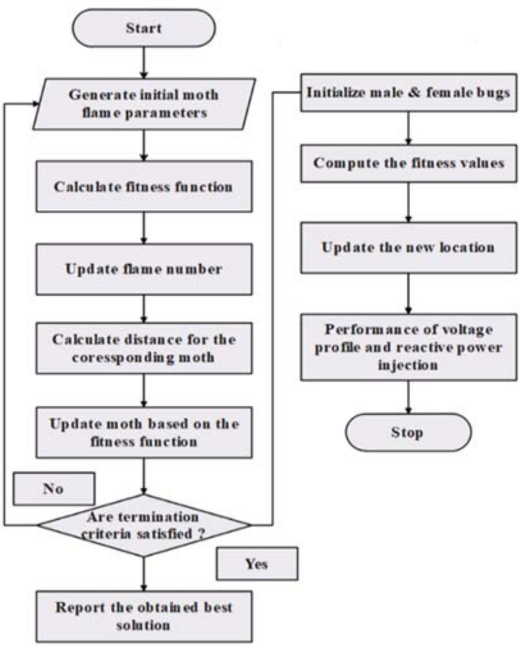

Fig. 1. Flowchart of proposed MFO-FSO.

5. Result and Discussion

The overall Simulink model of the proposed method is given in Figure 2.

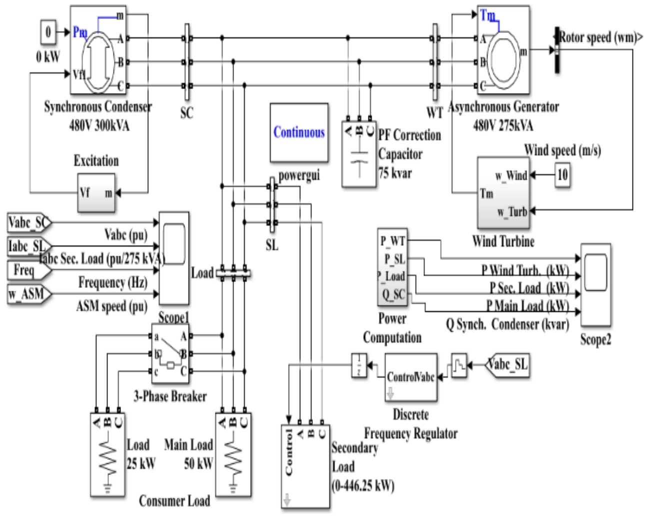

Figure 2. Simulink model for wind turbine induction generator

A. *Performance of STATCOM under Three-Phase Fault Conditions*

Figure 3 shows the wind farm with LLL-G fault when the system is presented without STATCOM. Figure 4 shows the B25 performance. The fault location of the 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 to 0MW in 15.11s. The reactive power of the wind turbine is decreased by 2 and 1MVAR at 15.1 and 15.11s respectively. Then this reactive power goes to 0. The pitch angle is going 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 the first fault, the B25 voltage is decreased from 1 to 0.4Pu at 15.1s and in the second fault, it is increased from 0.4 to 1.3 t 15.11s. The real power of B25 is 9MW which is changed 0, 3, and 0MW at the time of 15.1, 1, 5.11, and 16s respectively. The reactive power is changed from 2 to 11, 2, and 0 at the time of 15.1, 1, 5.11, and 16s respectively.

Figure 5 shows the wind turbine performance when the system has STATCOM during the LLL-G fault. The real power of the wind turbine is 9MW at 13.41s. In first and second faults of 15.01 and 15.11s, the real power is stabilized at 9MW. The reactive power is stabilized in 4.5MVAR at the first, second and third faults of 13.41, 15.01, and 15.11s respectively. The pitch angle is varied from 7 to 8deg when the wind farm run at 18s. The voltage of B25, real and reactive power is stabilized 0.9925Pu, 9MW, and 2Pu respectively. The voltage magnitude of STATCOM of all three faults is 0.98Pu. The reactive power is 1.65MVAR at 13.41s (first fault) and 1.6MVAR at 15.01 and 15.11s (second and third fault). Furthermore, this 1.6MVAR is stabled after the three faults. Table 1 shows the performance analysis of FACTS devices.

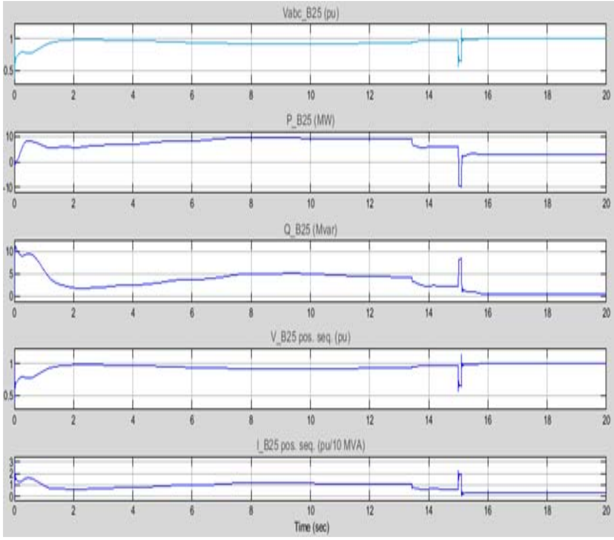

Figure 3. Performance of wind turbine

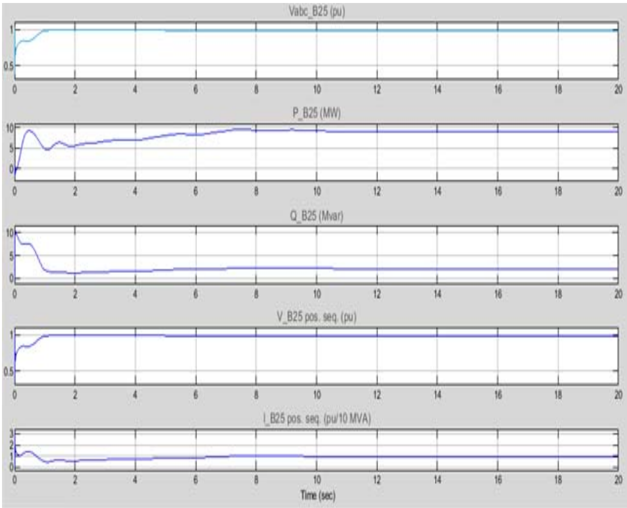

Figure 4. Performance of Bus B25

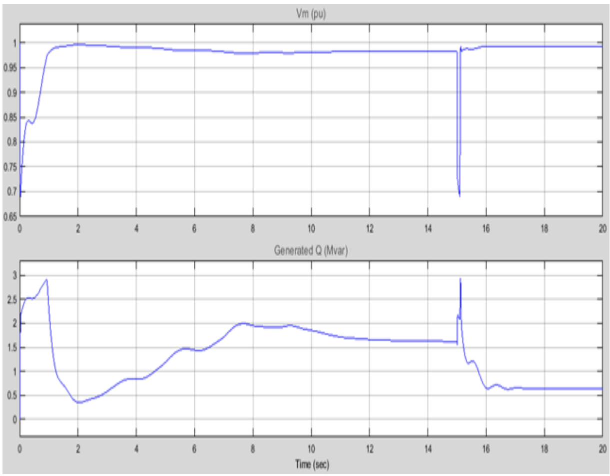

Figure 5. Performance of STATCOM

Table 1. Performance Analysis of FACTS devices

Parameters	SVC	TCSC	STATCOM	UPFC
Reactive Power (MVAR)	1.82	1.77	1.65	1.33
Voltage Magnitude (per unit)	0.9594	0.9732	0.9925	0.9972

B. Comparative Analysis

For comparison, the wind farm with the three-line ground fault (LLL-G) of STATCOM under LLL-G. Table 2 tabulates the comparative analysis of STATCOM. Table 2, it clearly shows that the proposed MFO-FSO achieves the maximum voltage magnitude of 0.9a, 925 p.u. with reactive power injection of 1.82 MVAR. While NGPC-based STATCOM [22] achieves the voltage magnitude of 0.9815 which is less when compared to propose MFO-FSO based STATCOM devices.

Table 2. Comparative Analysis of STATCOM

Parameters	NGPC-based STATCOM [22]	Proposed MFO-FSO based STATCOM
Voltage Magnitude (per unit)	0.9815	0.9925

Figure 6 illustrates the comparative analysis of STATCOM devices achieving a better voltage profile and reactive power injection when compared with existing NGPC-based STATCOM [22] devices.

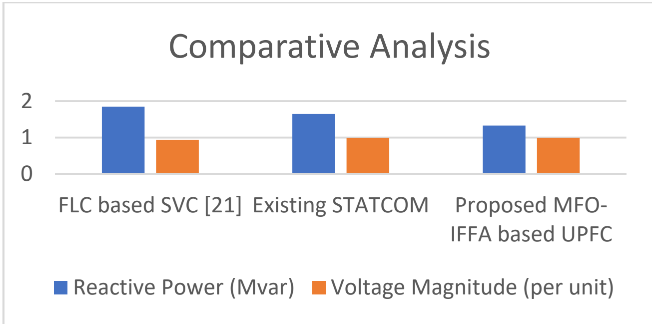

Figure 6.1 Comparative Analysis of STATCOM device

6. Conclusion

This study primarily focused on the multiple difficulties encountered when connecting the FACTS devices to a grid-coupled nonlinear wind turbine. When a defect occurs in a transmission line, the reactive power and voltage magnitude are injected using traditional means.

To provide the necessary reactive power during grid outages, the comparable model is shunt linked to the terminal to which the wind turbine system is connected. On the other hand, a unique control approach known as MFO-FSO is created to increase the efficacy of DFIG power. The modelling of DFIG-based wind turbines in light of current trends and the next stage of problem identification are both significantly assisted by this research. The wind system is coupled to the proposed MFO-FSO based FACTS model to provide the necessary reactive power during grid disturbances.

The simulation results clearly demonstrate that the proposed MFO-FSO model with STATCOM for the wind farm provides voltage stability of 0.9925 per unit with a reactive power input of 1.82 MVAR, outperforming the current NGPC-based STATCOM, which only provides 0.9815 per unit. Future work has expanded this research to include the analysis of wind turbine systems using permanent magnet synchronous generators while including various FACTS devices.

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