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Controller for Voltage Profile Improvement of Double Fed Induction Generator based Wind Generator

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Abstract - *Due to depleting fossil fuel reserves and growing environmental concerns, the world is shifting to renewable energy resources. From which wind energy generation is more attractive in terms of efficiency and stability. To maintain the wind turbine's voltage profile during the wind turbine's variable speed, a controller is needed to analyze the effects of varying wind speed on the wind generator's operation. For this purpose, this research proposes a controller for voltage profile improvement of DFIG connected wind turbine. The controller will be designed and simulated in MATLAB/Simulink, and results will be analyzed on different wind speeds and during the change in connected Load. The suggested controller design will be based on a stationary PI controller, and the effective performance will be enhanced by tuning the PI controller with Salp Swarm Optimization (SSO). The output will be compared with Whale Optimization Algorithm (WOA) and Grey Wolf Optimization (GWO).*

Keywords — *DFIG, Optimization algorithm, Voltage profile, wind speed*

I. INTRODUCTION

Modern society's living standard has become useless without a power supply [1, 2]. The power supply is very important these days because each household chores depends on electricity. Mostly the industrial area is high voltage consumer of electricity supply. The voltage stability is more important in getting awareness regarding DFIG, whereas voltage stability is a severe problem in power systems [3]. The system voltage changes when the Load is increased. Furthermore, the microgrid is created as a spearheading network of power generation for little scale grades to protect the environment, economic aspects, energy conservation and technical challenges, PV array, wind turbines, batteries, fuel cells compose a micro-grid [4].

There are numerous ways to control the voltage in DFIG research, which can be applied in different electric systems to maintain its stability under electricians' supervision. The Figure below shows the voltage system in DFIG [5].

When the DFIG based WTG supplies power independently, voltage flicker, sag, and swell can disturb the quality of the power supply to consumers. The sudden variations in the speed of wind also affect the power quality [6]. Hence, it is necessary to maintain the voltage in DFIG because it could be dangerous for the people in its surroundings. Therefore, according to the researcher's experiments in DFIG, they have given multiple ways to maintain the voltage and its usage [7].

In this paper, a thorough literature study was carried out. An optimal controller based on Salp Swarm Optimization (SSO) is proposed to improve the voltage profile of DFIG based wind turbine supplying the Load independently.

The paper's proceeding subsections include modeling the wind turbine, designing the proposed controller, applying optimization algorithm in the anticipated controller, the results from the intended controller, and finally, conclusions.

II. MODELING OF DFIG BASED WIND TURBINE GENERATOR PAGE LAYOUT

A classical model of induction machine in dq reference has been utilized in the proposed system. Whereas the detailed mathematic modeling of WTG can be accessed at [1, 8, 9]. Whereas the block diagram of the model considered for the proposed research is shown in Figure 1

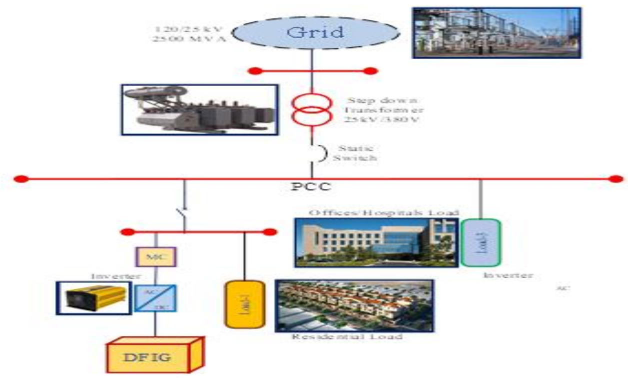


Fig.1 Proposed DFIG connected wind turbine

III. DESIGN OF SALP SWARM OPTIMIZATION BASED CONTROLLER PAGE STYLE

On account of these DGs' shifting nature, it is a necessity that the power grid ought to be interfaced with the DG unit and voltages so that adaptable operation of the framework is achieved [10]. Based on the voltages source, the DG unit, its power, and the control circuit are entirely reliant on the control's configuration. In grid-connected means of DG, where the grid controls voltage. The most likely things that these DG units will do is accomplish the Load requirement and uphold the excellence of the power that is being supplied. Due to this scenario, the voltages need to be controlled [11]. Subsequently, the DG unit's improved execution and activity can be achieved if the control mode of power is chosen wisely. The assessed regulator in the block diagram outline has appeared in Figure 2. It is fitting to specify that the estimation of reference voltages defines that microgrid control center (MGCC) [12] & phase-locked loop (PLL) may be utilized to quantify Vrms is given by [13].

In the proposed methodology, the intended controller will be applied during the stand-alone operation mode of DFIG. During this operation mode, any sudden variation in wind speed or change in Load will directly affect the inverter's output voltage. Hence, the measured voltage value of the inverter will be compared with the reference voltage value. The proposed controller will minimize the error between these two values. Initially, the controller is given with stationary gain values of the PI controller. With the optimization algorithm's application of the optimal PI controller gain's optimal value, the proposed controller will provide better results in terms of overextending, settle downtime, and the voltage waveform's rise time after any disturbances.

The recommended SSO controller's output will be matched with the GWO and WOA based controller and a controller without any optimization technique. The space-vector PWM has been utilized as a modulation technique for generating switching pulsations for an inverter [14]. The proposed controller will enhance power quality as per IEE Std 1547-2003 [15].

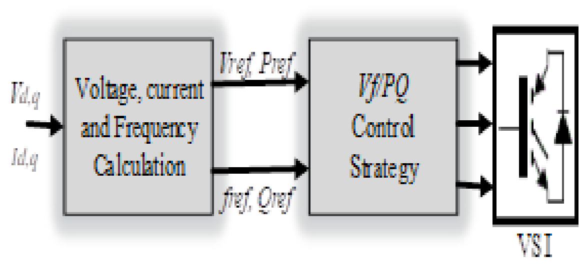


Fig 2. Block Diagram of Proposed Controller

A. PROPOSED CONTROLLER FOR VOLTAGE PROFILE IMPROVEMENT

The inside chart of the proposed controller is illustrated in Figure 3. The purpose of getting this control is to better control power targets' quality during any change in Load or unforeseen voltages. As shown in Figure 3 (left-hand side), the force regulator establishes two regular PI regulators. The force regulator is examined as an external circle is the proposed control system; the primary reason for an external circle is to create current reference values i_d^* and i_q^*.. Therefore, if the reference current is moderate, there will be a high-quality yield intensity of the inverter [16]. Owing to the regular PI regulator's constraint, increased esteems are set at appended esteem (Kp= 6.8, Ki= 7.6) [17], where the PI regulator isn't fit to accomplish ideal outcomes in managing control destinations naturally. With this arrangement, an ideal self-tuning for PI regulator gain regards improvement methods (GWO, SSO, and WOA) is given freely to achieve better control targets. The Load and the voltages are a couple of chief aims which ought to be overseen. The reference direction for controlling voltage depends upon their reference regards in this event. Further, the proposed controller with and without advancement smoothing out autonomously make control targets, however as the SSO is social cooperation and conduct is that it is a sort of Salp thought that have a straightforward barrel molded body and comparative tissues like snake structure in upgrading PI regulator gains, along these lines, it will give ideal control boundary to yield the best reference current vector when contrasted with GWO and WAO. Therefore, the estimations of reference current produced by an external circle are communicated as in equation (1) and (2) [18];

$$i_d^* = \left(V_{ref} - V\right)\left(K_{p\_v} + \frac{K_{i\_v}}{s}\right) \quad (1)$$

$$i_q^* = \left(f_{ref} - f\right)\left(K_{p\_f} + \frac{K_{i\_v}}{s}\right) \quad (2)$$

B. SALP SWARM OPTIMIZATION Title and Author Details

SSO is recently introduced by the swarm intelligence developed in 2017 by Mirjalili. ET. It is a population-based method. The motivation behind SSA to build a population-based analyzer by simulating 89 the swarm behavior of SALP in nature. The presentation of the first SSA as a 90 ELM coach has not been researched to date. The methods of swarm intelligence copy the knowledge of multitudes, groups, or rushes of animals. The primary establishment of these calculations begins from the aggregate behavior of gathering animals. For example, the ant can, on the whole, guarantee the endurance of a state without having a concentrated control unit. Nobody tells ants where and how a food source can be found; nonetheless, they accommodatingly find food at even far great ways from their homes. The two most celebrated calculations in this class are Ant Colony Optimization (ACO). And Particle Swarm Optimization (PSO). SSA tissues are related to jam fishes. They also move essentially equivalent to jellyfish, in which the water is siphoned through the body as the impetus to push ahead [74]. The state of a salp has appeared in Figure. 3. In a general sense, considering how their living, environmental factors are hard to access, it isn't easy to keep them in research facility conditions. One of the most captivating SALP behaviors, which is of attention in the paper, is their swarming behavior. In profound seas, SALP frequently structures a multitude called SALP chain. The fundamental explanation of this conduct isn't clear yet, yet a few analysts accept this is improved motion utilizing fast organized changes and foraging [75].

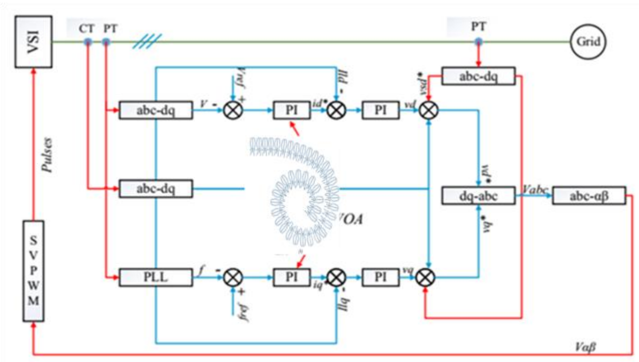


Fig 3.Application of SSO Algorithm for tuning of PI Controller

***1) Mathematical Formulation*:**

This sector presents the persuasive element for the planned maximization calculation alongside its numerical model. Salp's conspicuous bodied is a vertebrate and is renowned for making winding chain during its turn of events. Salps are most part referred to for their drive nature in water like a fly. To mathematically display the amassing of Salps, the self-assertive statement salp positions is made as depicted in Equation

$$K_1^{1:n} = rand(..)\left(ub_j - lb_j\right) + lb_{j,}\forall_j \in no.of\ variable \quad (3)$$

Where $K_1^{1:n}$ shows the initial position of salps, ub_j indicates the upper limit, lb_j represent the lesser limit. Besides, rand(..) is the numerical documentation utilized for generating an irregular number somewhere in the range of 0 and 1.

Besides, to mirror the Salp swarm component, a set chief and ally should be chosen. A Salp separate who is driving the entire multitude is viewed as the pioneer, while the other is considered an ally. In this turn of events, the pioneer is answerable for controlling the gathering towards a more secure situation with each continuous move. Condition (4) speak to the numerically deciphered rendition of the pioneer in sap swarm, where M speaks to the objective food, and K speaks to the two-dimensional situation of every Salp

$$K_j^1 = \{M_i + C_1\left(\left(ub_j - l_{bj}\right)C_2 + lb_j\right)C_3 \geq 0\ Mi - C_1\left(\left(ub_j - l_{bj}\right)C_2 + lb_j\right)C_3 < 0 \quad (4)$$

K_j^1 Shows the situation of the pioneer, M_i is the situation of the objective food in the j_{th} dimension, ub_j demonstrates the upper limit of the j_{th} measurement, lb_j indicates the lower furthest reaches of the j_{th} measurement, and C_1, C_2, C_3 are irregular numbers. The SSA speaks to a stretched series containing Salps; accordingly, this kind of improvement can get away from the restricted greatest or least arrangements. Condition (iii) states the investigating food pattern of the principle Salp by contrasting its improvement towards the goal food. This is one of the basic furthest reaches of SSA that manages the ally salps for getting food sources feasibly

$$C_1 = 2_e\left(\frac{4l}{L}\right)2 \quad (5)$$

L/L characterizes the ratio of the current emphasis to the most extreme expected emphases of the salp swarm. Additionally, arbitrary calculations in the scope of 0 to 1 are given to $C_2\ and\ C_3$ this estimation is answerable for the heading of the accompanying state for each J_{th} measurement dependent on the development size. Newton's law of movement assumes its part in deciding the ensuing pf supporters, as shown in Equation (6).

$$K_j^i = \frac{1}{2}at^2 + v_0 t \quad (6)$$

Where i_2 and K_i speaks to the circumstance of the followers. The mentioned expression signifies the way in J_{th} estimation for some ally expressed by the superscript of K. In Equation (3), t means the period and V_0 is the initial speed of the salp follower, which is relied upon to be zero. For the most part, time is implied by the redundancy number in the streamlining examination; thus, a stage size of 1 was picked for the time variable. An essential form of Equation (6) is appeared in Equation (7).

$$K_j^i = \frac{K_j^i + K_j^{i-1}}{2} \quad (7)$$

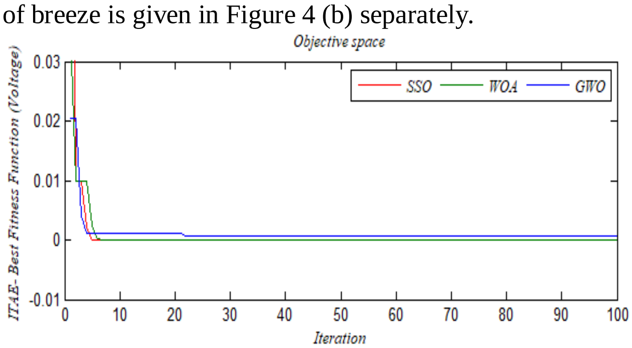
IV. CASE STUDIES OF PROPOSED TEST SYSTEM

The planned SSO is smeared to achieve the perfect implementation of a PI regulator to coordinate the Load and voltages of an MGS in two contextual analyses: the activity mode's progress and Load evolving mode. The planned control yield is contrasted with the PI regulator without enhancement, GWO and WAO tuned PI regulators. The framework's considerations are spoken to in per unit (p.u) framework, and reenactment is done in MATLAB/SIMULINK 8.3.0.532 (R2014a). The reproduction model of the planned framework has appeared in Figure 3. Two circumstances are investigated in this portion; the primary case joins the presentation of the planned regulator during a change in

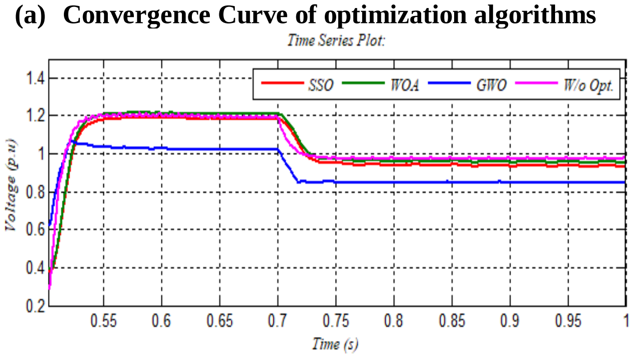
a) Simulation Result Case 1 (During Wind Speed Variation)

To analyze the proposed controller's effectiveness with and without optimization techniques at t=0.5s during varying wind speed (12m/s to 10m/s).from.The result obtained from the proposed SSO tuned PI controller is better in overshoot, rise time, and settling time.SSO tuned controller regulates voltage more efficiently, steady-state time of SSO is less too associated with the GWO & WAO tuned controller. Further, it is obvious from the plots for all three techniques that converge rapidity and steadiness of SSO.

The plot of wellness work acquired from every three streamlining methods appears in Figure 4(a). It is clear from this plot that the assembly speed and security of SSO is the most noteworthy when contrasted with the other two strategies due to its reasonable course of action for investigation. Besides, it is noticed that for the littlest estimation of capacity work, SSO is giving the ideal qualities for PI boundaries as delineated in Table-1, which confirms the best far-reaching convergence curve of SSO. The reproduction result acquired from the planned regulator for managing wind and voltage during the variation in the speed of breeze is given in Figure 4 (b) separately.



(a) Convergence Curve of optimization algorithms

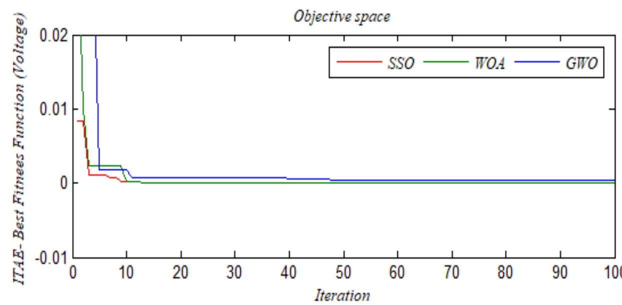


(b) Voltage Profile of DFIG after the change in wind speed at t=0.5s

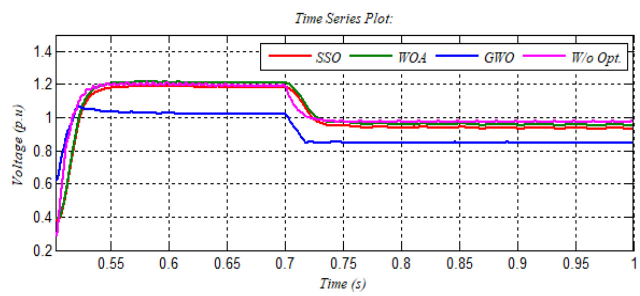
Fig.3 Simulations Results during a change in Wind Speed

b) Simulation Result Of Case 2 (During Variation In Load): The fitness function plots procure for voltage and Load during this experiment from SSO, GWO and WAO are shown in Figure 5 (a and b), respectively. These outlines show that the speed and stability of the SSO convergence curve are highest when contrasted with GWO and WAO because of its covenant planning for the exploration and exploitation process. Likewise, SSO gives the smallest fitness value and ideal values for the PI controller, which demonstrates its process as comprehensive for finding the best values.

To determine the proposed controller's efficiency during the load variation mode, the Load is decreased for 4KW to 2.5KW of time is t=0.7s. The result accomplished from the proposed SSO based controller seems to be better than GWO and WAO tuned PI controller with the smallest overshoot, rise time, settling time. The proposed controller regulates these parameters very easily when related to GWO and WAO with less steady-state time. It is also evident from these figures that the speed and stability of the convergence curve of SSO are highest when contrasted with GWO and WAO, and SSO is giving the lowest capability value along with ideal value for PI controller.



(a) Convergence Curve obtained from Optimization Algorithms



(b)Voltage Profile during the change in Load at t=0.7s

Fig.4 Simulations Results during the change in connected Load

c) Comparative Results For Both Cases: It can be noted that SSO, GWO, WAO for both the cases are applied for offline optimization, and when the ideal parameters for the PI controller are obtained, the attained parameters will be used in the PI controller. The PI parameters obtained from the offline optimization of all algorithms in both cases are summarized in Table 1. In both cases, SSO has marginally lower Integral Time Absolute Error (ITAE) indices during a change in wind speed and Load during the mode.

Further, the general performance of regulating voltage and Load in two cases is reviewed in the graph provided in Figures 4 and 5. In two cases, SSO accomplishes the least value for control objectives and limits the error between measured and reference values. Moreover, it can be promptly seen from Table-2 that the overall control objectives and ITAE guides having the error being minimized very efficiently. The SSO algorithm achieves the closest optimum solution with relatively minimized error compared to WAO and GWO. Thus, the overall performance of SSO is optimum and satisfactory. Whereas the voltage and current THD of the inverter is also within the specified limits in IEEE 1547-2003.

Table 1 Optimal parameters obtained by Optimization Techniques

Analysis	Mode	Method	Control Parameter		
Voltage Profile	Wind Speed Changing		K_p	K_i	ITAE
		SSO	-0.0079	0.0045	0.00000185
		WAO	-0.7461	0.0687	0.00007205
		GWO	-4.7052	3.6514	0.019525
	Load Changing		K_{p_load}	K_{i_load}	ITAE
		SSO	-0.0015	0.0008	0.00001158
		WAO	-0.4404	0.0412	0.00005780
		GWO	-3.922	2.1451	2.1451

To this end, Table 2 provides statistical results/analysis of all three algorithms after running each algorithm ten times. In all these cases. The obtained optimal results were similar regarding mean and standard deviation. There was no change in the solution up to predefined trials and 20 decimal places. Hence, SSO, WAO, GWO all have generated consistency in finding the optimal solution.

The SSO provides the fastest convergence compared to other algorithms. However, a pre-developed convergence curve may generate a low-quality solution. Among all three cases, SSO achieves optimal results in low computational time. As can be seen from Table 3, GWO and WOA have higher mean processing time than SSO. In the case of transient studies, the computational time is of great importance. Therefore, processing time weighs significant importance in the solution of algorithm steps.

Table 2 Statistical performance of considered optimization techniques

Method	SSO	WAO	GWO
Case1 Control Parameters during the variation in wind speed			
	Error value	Error value	Error value
Best solution	0.0007	0.002	0.007
Worst solution	0.0007	0.002	0.007
Mean	0.0007	0.002	0.007
Std Deviation	0.000	0.000	0.000
Processing time(s)	0.0063	0.1444	1.7296
Case 2 Control Parameter during load variation			
Best solution	0.0004	0.0006	0.003
Worst solution	0.0004	0.0006	0.003
Mean	0.0004	0.0006	0.003
Std Deviation	0.000	0.000	0.000
Processing time(s)	0.0540	0.0690	1.600

Table 3 Voltage and Current THD

Technique Parmeter	SSO	WOA	GWO	W/O Optimization
THDv (%)	0.80	0.90	1.69	5.64
THDv (%)	1.31	2.11	2.43	5.38

V. CONCLUSION

In this study, MG's significant characteristics are checked, and an enhanced controller is proposed to control and regulate MG parameters (voltage, active, and reactive power). The MG system consists of DFIG based wind generator to validate the proposed controller's effectiveness under both the MG's operating modes. The proposed controller utilized SSO for optimal tuning of the PI regulator to achieve optimum controller output during islanding and grid-connected MG mode and during the load variation. The proposed controller's simulation results satisfy the limits specified for voltage and harmonics in IEEE 1547-2003 standard. Subsequently, the proposed control strategy provides a better scenario for the MG system. The dependency on conventional power systems will be reduced with the increased utilization of renewable energy resources and reducing electric power costs.

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