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A Modified Damping Controller for Multi-Machine SCIG-WECS Grid Integration.

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Abstract
Electromechanical oscillations have led to significant blackouts around the world. The change in the rotor speed of the synchronous generator, leads to rotor angle deviation and this affects the power output of the system. This work aims to design a damping controller for a grid-connected wind farm using squirrel cage induction generator. The proposed power system stabilizer damping controller was optimized using walrus and Particle Swam optimization algorithms. Walrus optimization algorithm improves the stability of the system significantly.
Key words; *Damping controller, Renewable energy, Walrus, Electromechanical oscillation, Squirrel cage induction generator, Power system stabilizer. Particle warm*

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I. Introduction

Wind energy conversion system or wind farm system is one of the fastest growing types of renewable energy in power systems, in a wind farm, kinetic energy is always converted to mechanical energy and then to electrical energy, Wind turbines can work in two operation modes: stand-alone and grid-connected, but most of the turbines are operating in grid-connected systems, where the generated power from the wind farm is connected to the conventional grid[1]. The economic development of any nation depends on sufficient power to meet up with the rising demand, there is need to ensure stability from generation to distribution as the security of the system is important[2][3]. Due to its instability which can lead to unpredictable output, there is always a need to ensure maximum control of the system using different methods and techniques to achieve high efficiency[1][4][5]. The increase in the industrialization and global population has significantly increased the global energy demand, consequently, energy sources such as oil, gas and coal which are conventional, are limited and there is need for the renewable energy sources to be able to curb the challenge of growing global energy demand. One of the major advantages of the renewable energy source is that it is eco- friendly and unlimited in nature, and among the renewable energy sources, wind energy is more preferred as the cost of its production is always compared to those of conventional power plants as the variable wind speed turbines will always be used for the production of wind power[6].

Squirrel cage induction generator (SCIG), are mostly used more than other types of generators, this is because of their simple construction, easy operation, low noise and maintenance [7].The designs of induction generators for suitable performance should not be limited to the existing stator and the rotor structure, the squirrel cage induction generator operation will be more stable when it works with the saturation region so that the available terminal voltage could be handled. This generator is a type of generator that is being used in wind farm power generation, it is connected to the wind turbine with or without gear box, the generator generates torque from the wind power, and has high efficiency, reduce cost[8] [9][10].

Power system stability has to do with the ability of interconnected synchronous generators to return to synchronism after disturbances, there is always a need for synchronous machines to maintain optimum equilibrium between mechanical and electromagnetic torque, the study of the stability of the rotor angle deals with the examination of oscillations due to electromechanical oscillations found in the system because of small or large disturbances[11][12]. One of the major causes of rotor angle instability in the power system is electromechanical oscillation disturbances in the power system contribute significantly to the system instability and loss of synchronism if not properly dammed or controlled, we have local oscillation and inter-area oscillation, the local oscillation ranges between 0.2-0.7HZ, which is natural oscillating frequency, and the inter-area oscillation ranges between 0.3-0.8HZ, these oscillations could be disastrous to the system if not properly controlled[12][13].

Optimization plays a vital role in solving engineering problems that are complex, It is the art of selecting the best among given options, The objective of optimizations is to seek values for a set of parameters to minimize or maximize an objective function that is subjected to constraints [14].optimization algorithms can be broadly classified into metaheuristics, conventional, deterministic, and heuristic algorithms[15]. Metaheuristic optimization algorithms have become very attractive because of their special advantages over other techniques, they are used to solve multiple and complex and problems[16][17].

In this research, a metaheuristic optimization algorithm called the walrus algorithm has been proposed, WOA imitates natural behaviors of walrus, the inspiration behind the algorithm are the process of feeding, migrating, escaping, and fighting predators[18]. Particle swamp optimization algorithm is stochastic in nature based optimization algorithm that describes the intelligent movement of swamp, it is inspired by the social behaviors of animals and the advantage of mutual working sharing of the good information that could be helpful in discovering best place to forage for food, each of the particle in the swarm looks for its positional coordinates in the search space, called personal and global best. [19] [20] A proposed PSS damping controller is presented to damped electromechanical oscillation in SCIG grid connected system.

In the squirrel cage induction generators (SCIG), the power captured by the turbines of the wind farm is converted into electricity through the generator and this is transmitted to the conventional grid through the winding of the stator , for effective power generation, the speed of the induction generator should exceed the synchronous speed, the difference in speed could be so little and the wind turbine could be considered to be variable or fixed speed wind generator[21][6]. The wind integration into the grid has made the system to become more complex as the presence of the power electronic devices helps to stabilize the grid[22]. This design results in reduced losses, higher power density, and improved reliability among other factors. As the electric energy production from renewable energy such as wind among others has been accepted globally for energy problem potential solution the wind power generation using the SCIG has become increasingly attractive among many nations to solve the global energy crises. [23]

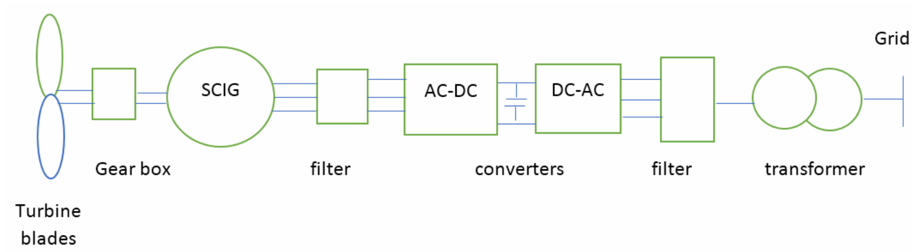

Fig 1.1. Grid-connected SCIG-based wind[6]

The integration of the wind farm into the multi-machine system using SCIG forms the grid system. The transmission system are connected to two different system which is called the tie line, this makes the electromechanical oscillation to have a complex nature[12][13]

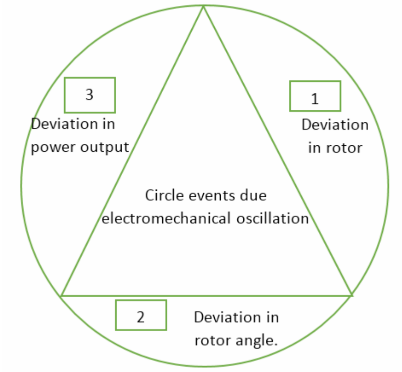

Fig.1,2 circle of events due to electromechanical oscillation[12].

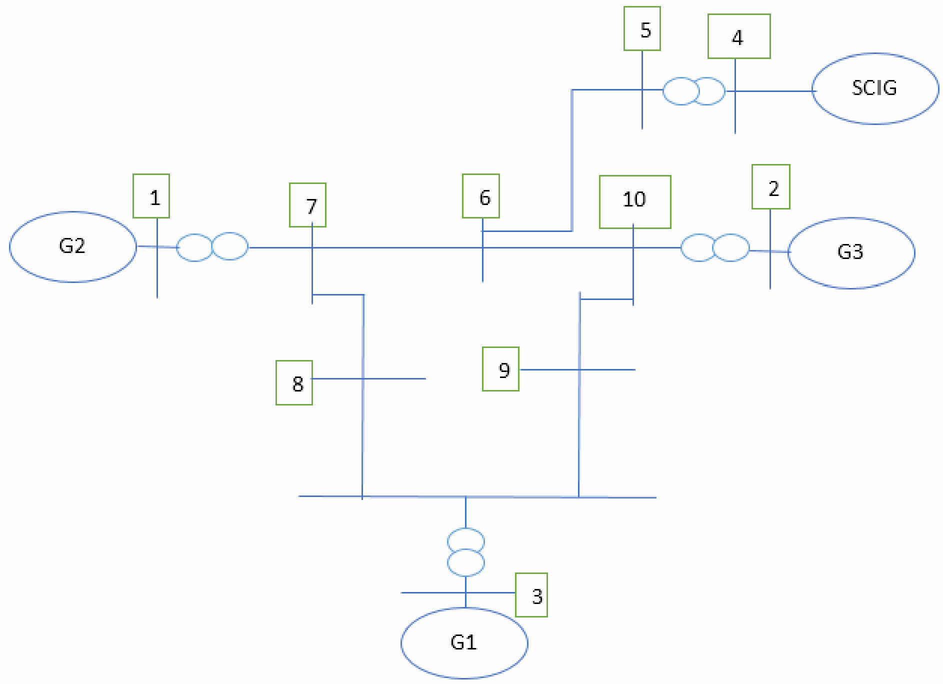

Fig.1.3. WSCC Multi-machine with WECS using SCIG[13].

II. Materials and Methods

The simulation was caried out using MATLAB/Simulink software 2021, window 10 system Intel(R).

2.1.1 Objective Function Formulation for Damping Controller Design.

The objective function adopted for this work is shown below.

ITAE(3.1)

Integral time absolute error is the objective function adopted for this work.

The ITAE performance index is high due to the advantage of producing fast rising time, reduces overshoot, and fast settling time than integral time square error (ITSE), integral square error (ISE), integral absolute error (IAE),

The objective of the PSS is to provide torque to the system excitation of the generator so that the electromechanical oscillation can properly dampen the oscillations that could occur due to disturbances.

(3.2)

The constrains.

, ,

[30] [35].

The modelling components in this work consist of the excitation system, torque loop angle, turbine governor and the generator. The power system model that is used to relates the renewable energy source in this work is squirrel cage induction generator. This includes the wind turbine, generator, filters, machine, and the grid side coveters[24]. modellings of the power systems were adopted through studies [25][26] [27][28][29]

2.1 Power System Stabilizer Design

The concept of a power system stabilizer was first introduced in in the year 1969, PSS is a primary and highly cost-effective for damping oscillation in a power system, the generator output can be controlled by making sure that the excitation voltage is fully controlled, PSS will always provide the synchronous generator excitation system with supplementary input signal, PSS can generate additional synchronizing torque to be in phase with the speed deviation, as result of this the oscillations can be damped out and the stability the system is fully retained. Damping controllers play a vital role in in power system damping scheme, they decide the switching control of the entire system, for this work, the lead-lag controller is being proposed for the effective implementation of this research. They are very popular and are one of the most dominant controllers used for damping oscillations in power systems, they are cost-effective and have the assurance of stability [32].

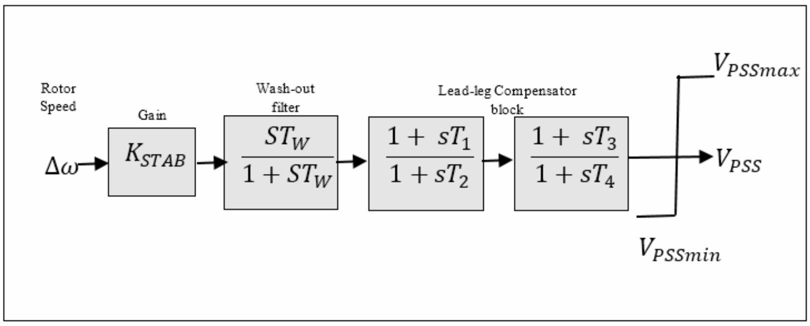

Fig. 2.6 lead lag controller [32].

Kstab- PSS gain, TW-PSS washout time constant, T1, T2- PSS lead compensating time constant T3, T4-PSS Lag compensating time constant Vpss- Stabilized output signal[32][13]. The objective of the PSS is to be able to provide torque to the system excitation of the generator so that the electromechanical oscillation can properly dampen the oscillations that arose because of disturbances.

2.2.1 MODELLING OF THE MULTI-MACHINE SYSTEM.

The modelling of the system is done using the deferential algebraic equation for the test system dynamic, for the n synchronous machine differential equations and the automatic voltage regulator.

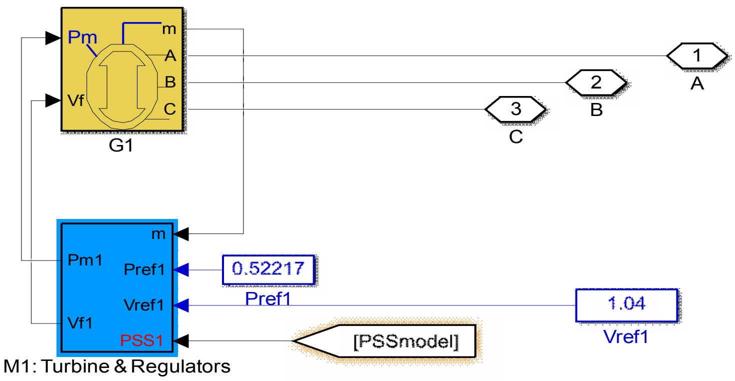

Fig 3.2 Simulink representation of the synchronous machine.

2.2.2 EXCITATION SYSTEM.

The excitation system is responsible for the regulation of the generators field and bus voltages.

(2.1)

(2.2)

(2.4)

(2.5)

(2.6)

field voltage of the generator, time constant and feedback gain, [48] [49][50][51]

2.2.3 THE TORQUE ANGLE LOOP.
This is used to describes the rotor angle and the change in the rotor speed when there is a mismatch between the two torques in the mechanical system of the synchronous generator.
(2.7)
(2.8)

2.2.4 THE TURBINE GOVERNOR.
The turbine governor is responsible for regulation of the grid frequency of the power system, especially when there is a change in balancing of the load and generation of power, and therefore this can be achieved by adjusting the input of the generator torque.
2.9)
Where is the governor droop

2.2.5 SYNCHRONOUS MACHINE.
The synchronous machines send the output power into the grid.

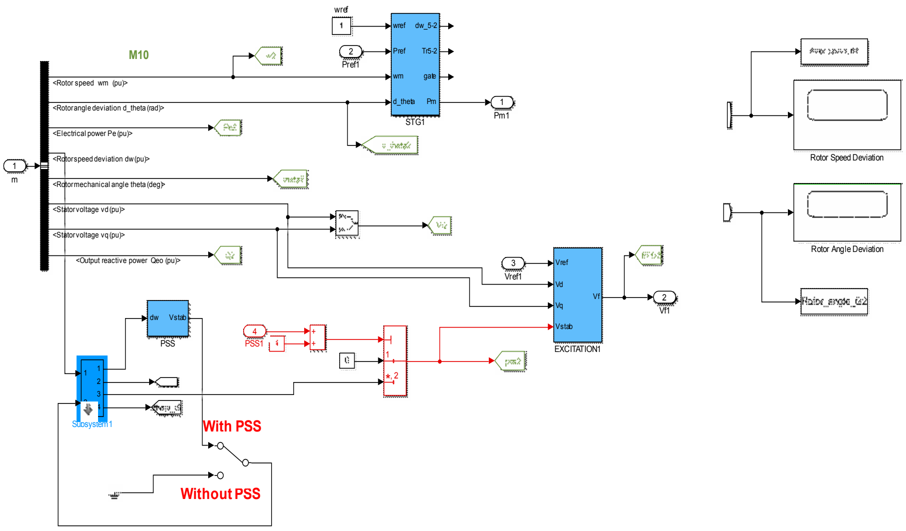

Fig 3.3 Simulink representation of the synchronous machine and excitation.

2.10)
The algebraic equation of all the stators in the multi-machine[48]
+ 2.11)
+ 2.12)
+ 2.13)
+ 2.14)
Therefore.
, [50][51] 2.15)
= 2.16)
.... , 2.17)

The power system of the grid consists of n number of buses and m numbers of generators, and these can be shown in the algebraic equation below.

Where I=1, ...m

Where i=m+1........n
2.21)
The load active power and reactive power are represented by PL and QL
, respectively. Yej–. denotes the power system admittance.

matrix and θ is the bus voltage V angle. The admittance matrix load element in power lines is reduced by the order reduction method, as in equation (24)
The power system linear model is described using equation (24), where x is the system state vector variables, A is the state space matrix of the system, B is the system input matrix, and u is the system control input vector.
2.22)

The network of the n machines can be represented below as

= [50][51] (2.23)

2.3 **MATHEMATICAL MODELLINGS OF SCIG:**
The modelling of the system consists of aerodynamic, generator model, generator side converter, grid side converter, and the filters.

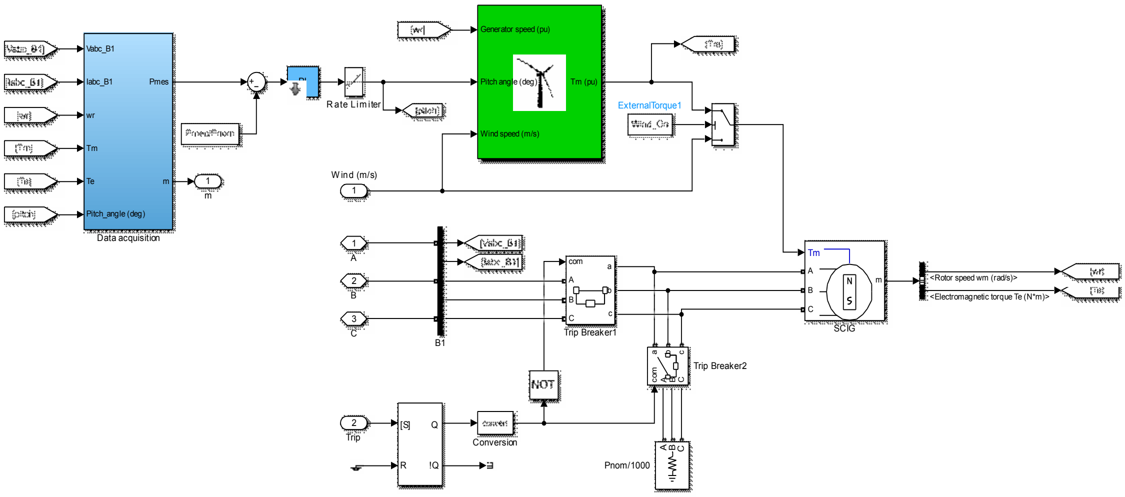

Fig.3.4 Simulink representation of the WECS

The mathematical modellings of the system of the systems are

2.4.0 AERODYNAMICS.
The wind turbine is used for the conversion of wind kinetic energy to mechanical power this can be expressed in the equation.
(2.24)
Where is the density of the air, . the blade of the swept of the turbine where is the speed and is the lower coefficient which express the relationship between the tip speed ratio and the pitch angle
0.4. -5) exp (), and
where speed of the rotor
The drive train uses the mechanical power to drive the generator.
(2.26)
(2.27)
(2.28
Where, the torque is the generator rotor speed. inetial,

2.4.1 GENERATOR MODEL
= -2.29)
= = -2.30)
= = - 2.31)
= = - 2.32)
where.

2.33)
In the squirrel cage induction generator, the rotor terminals are shorted, and the rotor currents are not measured.
The active and reactive power of the generator (SCIG)

) (2.34)
) (2.35)
The electromagnetic toque is given as

In the squirrel cage induction generator, the rotor terminals are shorted, and the rotor currents are not measured.

2.4.2 THE GENERATOR-SIDE CONVERTER.
The generator side converter or controller convert rotor speed and current into electrical signals that will give signal to the converters power caches the maximum power from the wind power to be able to control the electromagnetic torque in the system, it controls active and reactive power The vector control technique for MSC is mainly used to maximize the extracted power from the wind turbine by controlling the SCIG speed, it has a nested-loop structure with a faster inner loop and a slower outer loop as. The proposed controller is PID.
(3.37)
Where is the blade angular velocity, is the tip speed ratio.
(3.38)
=

2.4.3 THE GRID SIDE CONVERTER,
The goal of the grid side converter is to control the active and the reactive power and to also keep the stability of the DC line voltage[50].
(3.41)
(3.42)

2.4.4 THE FILTERS EQUATION.
The filter consists of LCL, back-to-back capacitor,
The differential equation in the d and q axis of the rotating frame can be obtained the generator and the grid side.
= (3.43)
= (3.44)
= (3.45)
= (3.46)
The capacitor
(3.47)
(3.48)
The network of the SCIG can be represented as
= (3.49)

The network of multi-machine and the WECS using SCIG integration is represented below.

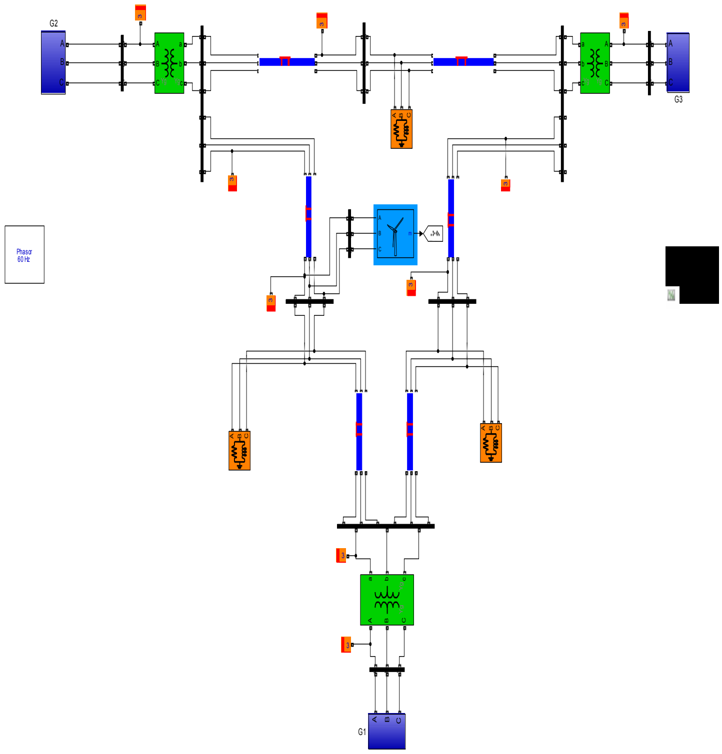

Fig.3.5 Simulink representation of multi-machine with WECS integration.

= [50][51] (3.50)

III. Results and Discussions

The section of this work presents the results obtained from the simulation process through the implementation of the proposed methodology on MATLAB/Simulink software. Firstly, the analysis was carried out using the 3- machine 9 bus test system with the integration of WECS into the system the proposed walrus optimization algorithm performance was validated using PSO in each case. The data for this work were obtained from studies [30][29][31][32][33]

3.1 Uncontrolled grid system: the uncontrolled system of WSCC with the integration of WECS simulation studies are shown in the graphs below, the speed and the rotor angle deviation of the system.

To obtain the Eigen values and the corresponding damping ratio, the system was linearized using the [a, b,c,d]=lindmod('WSCC') command, this express the system stability. As expressed in table 2.1

Table 2.1; Uncontrolled eigen values Parameters

Mode	Eigen Values	Damping ratio
1	0.0502 j0.06525	-0.0040
2.	-0.0016 + 0.0000i	0.0000
3.	-0.0021 + 0.0000i	0.0000
4.	-0.0001 + 0.0000i	0.000
5.	-0.0023 + 0.0000i	0.000

3.2 Controlled grid system

The table in the figure 2.2 shows the eigen values and their corresponding damping ratios as obtained through the linearization process.

Table 2.2; Eigen values of a controlled system.

Modes	PSO-PSS	WaOA-PSS
1	-1.7320 0.43000i, 0.3561	-2.2241 0.5340i, 0.6456

2	-0.0019 0.00621i, 0.0760	-0.0387 0.0047i, 0.0290
3	-0.0501 0.0000i, 0.0301	-0.0656 0.0007i, 0.0356
4	-0.0003 0.0090i, 0.0038	-0.0069 0.0031i, 0.0176
5	-0.0001 0.0038i, 0.0031	-0.0003 0.0066i, 0.0066

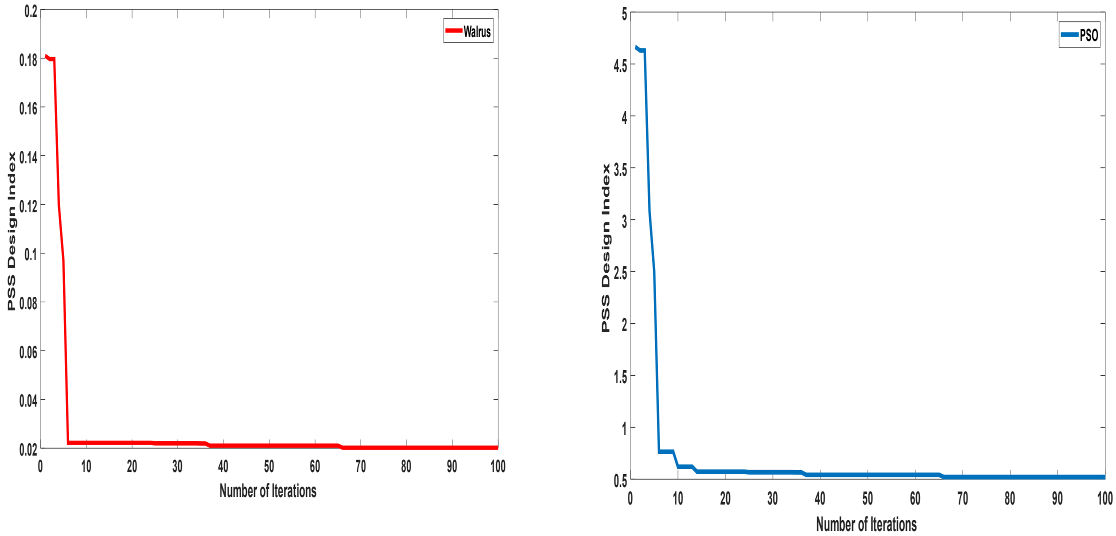

Fig 2.2 WaOA and PSO iteration convergence curve

Table.2.3 PSO and WaOA search algorithm of G2 for PSS Optimal Parameters

Algorithm/parameters	Kpss	T1	T2	T2	T4
PSO-PSS	8.8453	0.007	0.06	0.8	0.09
WaOA-PSS	0.1360	0.1685	0.4089	0.8051	0.7422

Table 2.4 PSO and WaOA search algorithm of G3 for PSS Optimal Parameters

Algorithm/parameters	Kpss	T1	T2	T2	T4
PSO-PSS	6.943	0.044	0.078	0.44	0.335
WaOA-PSS	23.1260	0.1685	0.709	0.41	0.5422

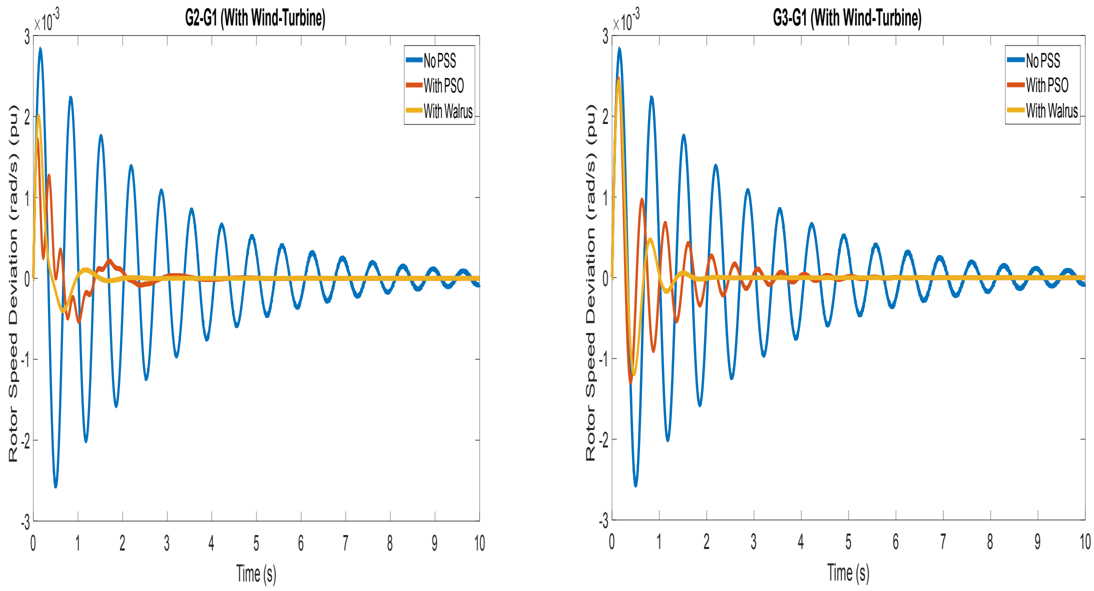

Fig2.3. Controlled and uncontrolled rotor speed deviation

Table 2.5 Rotor speed deviation Stability analysis with WECS integration

Rotor speed deviation analysis of Stability for WSCC 3- Machine 9 bus System with WECS integration				
Algorithm	Rise time(s)	Settling time(s)	Rise time(s)	Settling time(s)
Without PSS (based case)	0.150	9.980	0.150	9.471
PSO-PSS	0.097	3.781	0.136	5.233
Walrus-PSS	0.113	1.620	0.121	1.488

Under the operating condition, from table 2.5 the settling time of rotor speed deviation of generator 2 out of 10s simulation time with NO PSS settled at 9.980s. PSO- PSS settled at 3.781s while WaOA- PSS settled at 1.620s The settling time of rotor speed deviation of generator 3 with NO PSS controller settled at 9.971s. PSO- PSS controller settled at 5.233s while WaOA- PSS controller settled at 1.488s

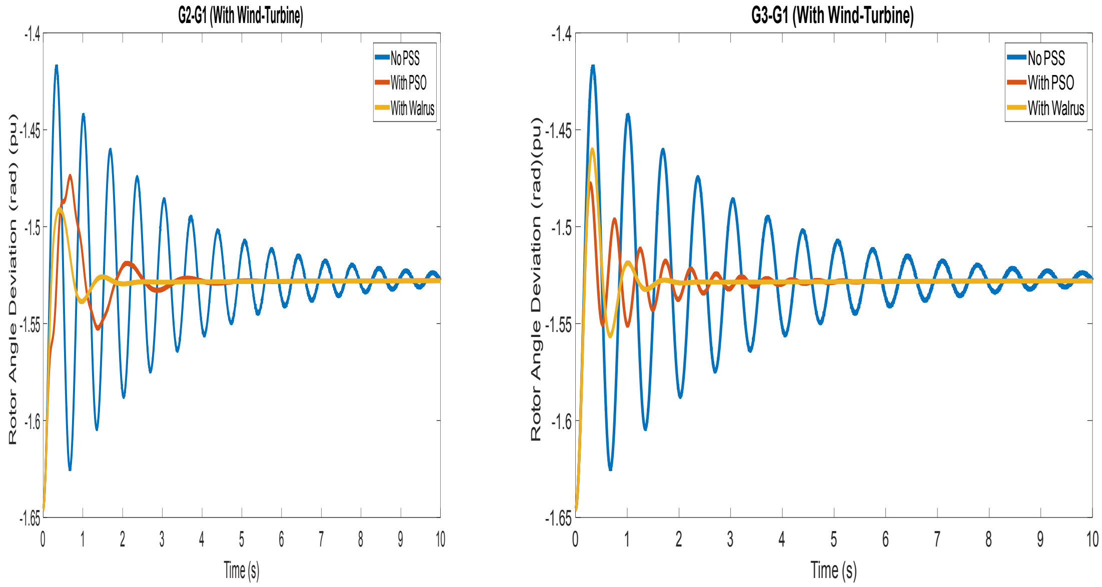

Fig 2.4 Controlled and uncontrolled rotor angle deviation and

Table 2.6 Rotor angle Stability analysis with WECS integration

Rotor angle analysis of Stability for WSCC 3- Machine 9 bus System with WECS integration				
Algorithms	Rising time(s)	Settling time(s)	Rising time(s)	Settling time(s)
Without PSS (based case)	0.331	9.94	0.327	9.94
PSO-PSS	0.672	4.287	0.295	5.299
Walrus-PSS	0.440	1.723	0.340	1.663

IV. Conclusion

The focus of this work was to design a damping controller using walrus optimization algorithm to ensure that the stability of the system is improved. For the validation of the performance of the proposed algorithm, Particle swarm optimization algorithm was used. The settling time of the rotor angle deviation of WaOA- PSS settled at 1.723s, while the rotor speed of the proposed WaOA- PSS damping controller settled at 1.663s, and the damping ration stood at 0.6456, which improved the stability of the system significantly through the quantitative analysis of the nonlinear time simulation results.

Abbreviation

PSS Power System Stabilizer

WSCC Western system coordinating Council

WaOA Walrus optimization algorithm
DFIG Double-fed inductor generator
SCIG Squirrel cage induction generator.
FACTS Flexible AC Transmission devices
MARC Model reference adaptive controller
WECS Wind energy conversion system

= the constant of open circuit in the q axis
Field voltage
=synchronous and sub- synchronous reactance in the d and q axis
= synchronous speed and rotor speed
, electrical and mechanical torque
H, C, rotor angle, inertial constant, damping coefficient, and armature resistance.
generator terminal voltage of d-axis, d, and q axis stator current.
= flux linkage due to transient emf in the d and q axis damper coil.
= reference of the Excitation voltage.

feedback gain.
=Governor time constant.
=Load active and reactive power, power system admittance matrix.
is the flux linkage of the stator circuit,
represent the magnetizing inductance,
, is the flux linkage of the of the magnetizing inductance.
= torque, rotor speed. inetia

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