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Hybrid Power System Design for Damping Electromechanical Modes of Oscillation in Grid Connected Machines

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Abstract: **Due to the natural intermittent nature of wind and solar PV, autonomous wind/PV systems for renewable energy typically require energy storage or other sources of production to form a hybrid system. in this paper objective of the designing of a grid dynamics controller equipped with IGBT based bridge structure for stabilizing various electrical parameters on the grid system while its renewable energy-based grid integration. And the controller has to be designed with modulation technique, for both voltage and current at particular frequency following stabilization which is both simple in implementation and operation. And the comparative analysis of techniques used has to be carried out with AI-based optimization algorithms for studying its effectiveness. The results of the THD % of voltage in the system having no controller was found to be 3.32 %. in the system having adaptive neural PSO switching of grid dynamics controller, the distortion level came down to 1.96%. The hybrid system with solar wind energy was further integrated with the grid and was analyzed for the rotor angle stability in the two machines. It was concluded that out of the three controls for grid dynamics controller the artificial intelligence-based adaptive neural PSO switching was found to be best with maximum stability of machines.**

Keywords: **PSO, Solar, Wind, THD.**

I. INTRODUCTION

Photovoltaic power generation is less restricted by Region, in addition, it has the characteristics of safety, reliability, no noise, low pollution, no need of fuel consumption and short construction period. If it could be independent power supply, it doesn't need to set up a transmission line. The structure of photovoltaic power generation system is shown in Figure 2. When light is constant, according to the solar energy output volt ampere characteristics and the internal structure, the photovoltaic current will not change with the working state of the PV array. Therefore, a circuit can be used to simulate the output characteristics of photovoltaic arrays.

Due to the wind and solar energy are highly complementary to each other, the wind-solar hybrid generation system makes up for the defects of wind power and photovoltaic independent system on resources. Wind-solar hybrid generation system can be divided into two categories, it is the conversion power systems to power after the related electrical equipment interface, power to meet the output requirements, the final power generation. The grid connected wind generator system with complementary use refers to the cluster configuration, to a certain extent, the operation of the wind farm is a large wind turbine, which is directly connected to the power grid.

II. LITERATURE REVIEW

Hirofumi Matsuo et al. [1] This paper proposes a unique standalone hybrid power generation system, applying advanced power control tech- niques, fed by four power sources: wind power, solar power, storage battery, and diesel engine generator, and which is not connected to a commercial power system. Considerable effort was put into the development of active-reactive power and dump power controls. The result of laboratory experiments revealed that amplitudes and phases of ac output voltage were well regulated in the proposed hybrid system. Different power sources can be interconnected anywhere on the same power line, leading to flex- ible system expansion.

Saheli, M. A et al. [2] the development and modeling is reported of a photovoltaic (PV)/wind/diesel hybrid power generation system for a household in Winnipeg, Manitoba, Canada. For optimizing and determining the feasibility of the system, Homer simulation software is utilized. Various system configurations are investigated and comparisons are made using an optimization approach. The results obtained with Homer software demonstrate that a hybrid wind/PV/diesel/battery power generation system has the lowest cost and the highest efficiency of the systems considered. The system helps reduce emissions of pollutants and greenhouse gases.

Ping HE et al. [3] Energy crisis and environmental pollution caused by conventional energy power generation make renewable energy such as wind energy and solar energy as new alternative energy sources. The complementarity of wind-solar hybrid generation technology will be the focus of future research. This paper briefly introduce the current situation of the development of wind-solar hybrid generation system, the principle and analysis method of low frequency oscillation in power system are summarized. This paper provide a reference for further study of the influence on the characteristics of low frequency oscillation in power grid.

Hu, Rui et al. [4] this paper presents an overview of researches on power system stability with high wind power penetration including analyzing methods and improvement approaches. Power system stability issues can be classified diversely according to different considerations. Each classified issue has special analyzing methods and stability improvement approaches. These analyzing methods and stabilization techniques are presented and discussed in this paper.

III. Objective

There are following key points are to be considered while designing in present work

- Designing of a hybrid solar PV system with Wind energy system in MATLAB/SIMULINK so as to enhance its output capacity before its integration with the grid. The two energy systems are to be modelled with variable input parameters such as variable irradiation level and variable wind speed.
- Designing of a grid dynamics controller equipped with IGBT based bridge structure for stabilizing various electrical parameters on the grid system while its renewable energy based grid integration.
- The controller has to be designed with modulation technique, for both voltage and current at particular frequency following stabilisation which is both simple in implementation and operation.
- Comparative analysis of techniques used ahs to be carried out with AI based optimization algorithms for studying its effectiveness.
- Enhance the system reliability and efficiency by integrating it with the two machine power system via a transformer with the desired grid voltage and frequency and study the effect of a renewable energy integration with grid on stability of machines

IV. Methodology

Various modeling techniques are developed by researchers to model components of HRES. Performance of individual component is either modeled by deterministic or probabilistic approaches. This method discusses the basic modeling structures of solar energy system, and Wind energy system along with modeling of PSS controls.

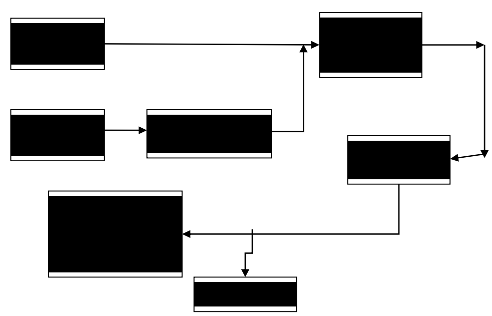

Fig. 1 Proposed Hybrid energy system topology

A. PV Module modeling

PV cells have single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I. A simple equivalent circuit of PV cell is shown in Fig. 6.

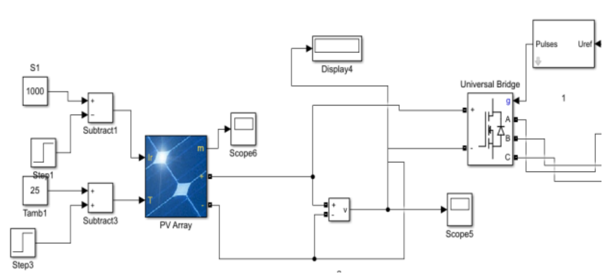

Fig. 2 Modeled solar system

A cell series resistance (Rs) is connected in series with parallel combination of cell photocurrent (I_{ph}),exponential diode (D), and shunt resistance (R_{sh}) , I pv and Vpv are the cells current and voltage respectively. It can be expressed as

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$$

Where:

I_{ph} - Solar-induced current

I_s - Diode saturation current

q - Electron charge (1.6e^{-19}C)

K - Boltzmann constant (1.38e^{-23}J/K)

n - Ideality factor (1~2)

T - Temperature ^{0}K

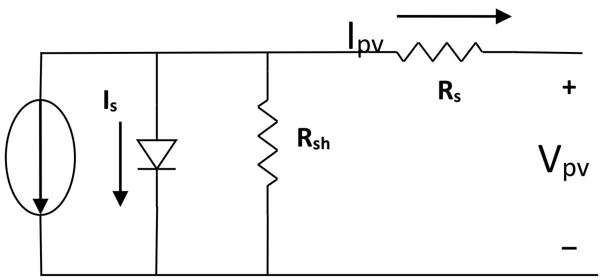

Fig. 3 Equivalent circuit of solar pv cell

The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000}$$

Where:

I_{SC} Short-circuit current of cell at STC

K_i Cell short-circuit current/temperature coefficient (A/K)

I_r Irradiance in w/m

T_C ,T_r Cell working and reference temperature at STC

A PV cell has an exponential relationship between current and voltage and the maximum power point (MPP) occur at the knee of the curve as shown in the Fig 4.

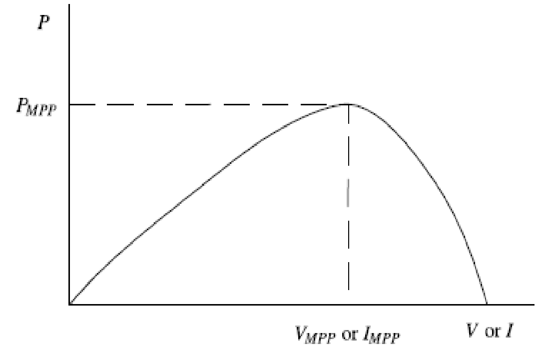

Fig. 4 Characteristic PV array power curve

Table 1: PV module Parameters	
Maximum Power	213.5 Watts
Number of parallel strings	40
Number series modules	10
Open circuit voltage	36.3 Volts
Shot circuit current	7.84 Ampere
Irradiation	500 to 1000 wb/m^2
Temperature	25^{0}C

B. wind energy system modeling:

Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. The components of wind turbine have been modeled by the following equations [8-10].

Output aerodynamic power of the wind-turbine is expressed as:

$$P_{Turbine} = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3$$

where, ρ is the air density (typically 1.225 kg/m3), A is the area swept by the rotor blades (in m2),CP is the coefficient of power conversion and v is the wind speed (in m/s).

The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v}$$

where ω_m and R are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively.

The wind turbine mechanical torque output m T given as:

$$T_m = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3 \frac{1}{\omega_m}$$

The power coefficient is a nonlinear function of the tip speed ratio λ and the blade pitch angle β (in degrees).

Then Power output is given by

$$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}} v^3$$

A generic equation is used to model the power coefficient C_P based on the modeling turbine characteristics described as:

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)}$$

For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor, so the maximum power is extracted continuously from the wind.

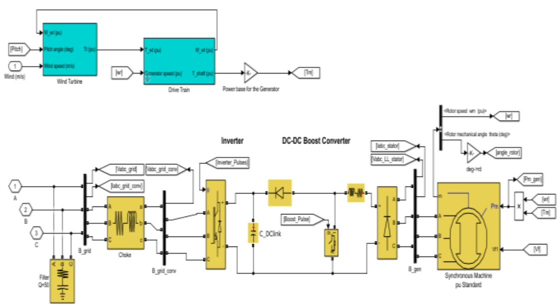

Fig. 5 modeled Wind system

This mechanism uses the variable torque output w_m and tries to optimize the output current and voltage waveform to its maximum value.

Table 2 : PV module Parameters	
Maximum Power	213.5 Watts
Number of parallel strings	40
Number series modules	10
Open circuit voltage	36.3 Volts
Shot circuit current	7.84 Ampere
Irradiation	500 to 1000 wb/m^2
Temperature	25^{0}C

C. Hybrid solar/wind MATLAB/SIMULINK modeling

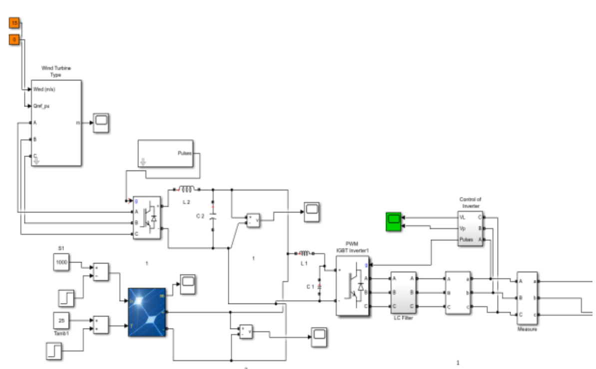

Fig. 6 Modelled hybrid PV/WIND system in MATLAB/SIMULINK

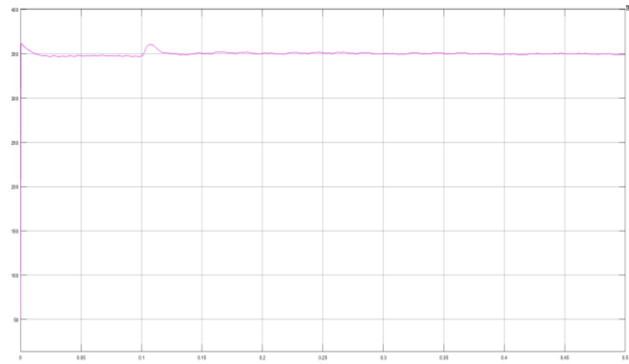

Fig. 7 DC output from hybrid system before feeding into inverter and grid

D. Power system modeling:

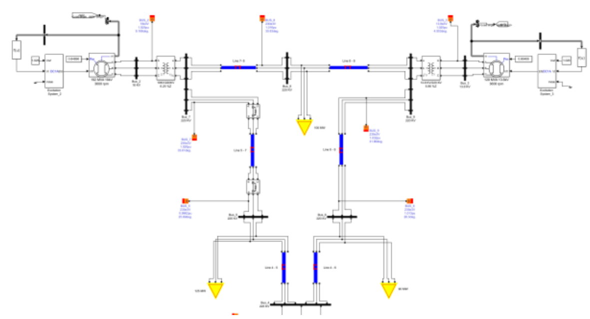

Fig. 8 Modeled Power system in MATLAB/SIMULINK environment

E. grid dynamics controller having programmable hysteresis switching control

Programmable Integral controller technique is chosen as to combine with hysteresis current control because to overcome undesirable drawback of classical hysteresis current controller. The input of programmable controller is an error in the voltage between the reference voltage and output voltage from the hybrid system for each phase. The advantages of this controller is its simple implementation, fast transient response, direct limiting of device peak current and practical insensitivity of voltage ripple.

The output is then integrated with the hysteresis current control for removal of the distortion in current outputs. In programmable hysteresis control, there are two upper bands and lower bands in order to change the slop of grid dynamics controller output current based on their level voltages, +Vo, 0 and -Vo. The idea is to keep the current within the main area but the second upper and lower bands are to change the voltage level in order to increase or decrease the di,/dt of output current.

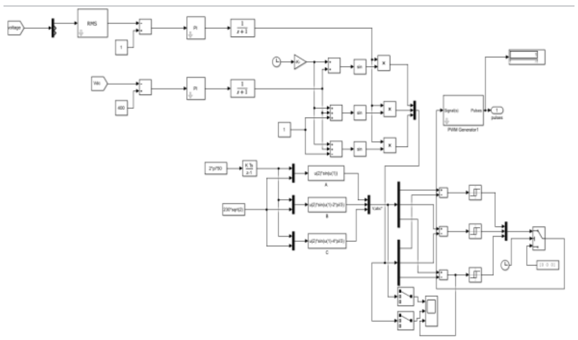

Fig. 9 PI-hysteresis control of stabilizer in MATLAB/SIMULINK

Proportional Controller (proportional-integral controller) is a feedback controller which drives the grid dynamics controller to be controlled with a weighted sum of the error (difference between the output and desired set-point) and the integral of that value. The output voltage from the controller was analyzed for its total harmonic distortion percentage calculation

F. adaptive neural PSO switching of grid dynamics controller

ANNs are information processing systems that simulate the behavior of the human. ANNs obtain the inherent information from the considered features and learn from the input data, even when our model has noise. ANN structure is composed of essential information processing units, which are neurons.

They are defined into several layers and interconnected with each other by defining weights. Synaptic weights show the interaction between every pair of neurons. These structures distribute information through the neurons. The mappings of inputs and estimated output responses are calculated through combinations of different transfer functions. We can use the self-adaptive information pattern recognition methodology to analyze the training algorithms of the artificial neural networks. The most commonly used computation algorithm is the error back propagation algorithm.

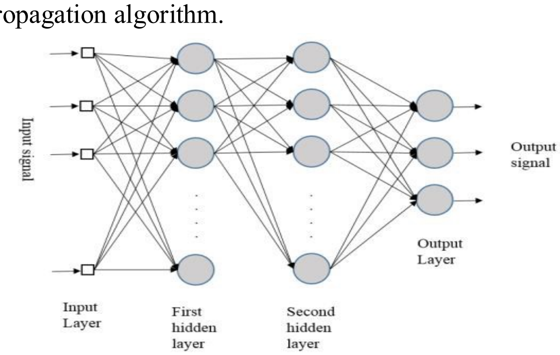

Fig 10 Architectural Graph of an MLP Network with Two Hidden Layers.

Neural networks can be divided into single-layer perception and multilayer perception (MLP) networks. The multilayer perception network includes multiple layers of simple, two state, sigmoid transfer functions having processing neurons that interact by applying weighted connections. A typical feed-forward multilayer perception neural network consists of the input layer, the output layer, and the hidden layer. The multilayer perception (MLP) with the back propagation learning algorithm is used in this study because numerous previous researchers used this type of ANN, and it is also a general function approximation.

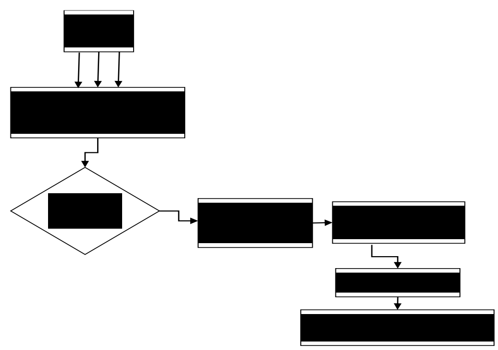

Fig. 11 PSO – NN controller Technique implemented in MATLAB/SIMULINK

The voltage parameter is first optimized via PSO algorithm and is then trained through neural network. The development of ANN models was based on studying the relationship of input variables and output variables. Basically, the neural architecture consisted of three or more layers, i.e. input layer, output layer and hidden layer as shown in Fig. 1. The function of this network was described as follows:

$$Y_j = f(\sum_i w_{ij} X_{ij})$$

where Yj is the output of node j, f (.) is the transfer function. wij the connection weight between node j and node i in the lower layer and Xij is the input signal from the node i in the lower layer to node j.

V. Results

A. Implementation Details

This results comprises with an analytical and numerical description of proposed algorithm for sentiment analysis of a power buffer which is simulated to obtain the performance of the proposed algorithm.

In order to evaluate the performance of proposed algorithm scheme, the proposed algorithm is simulated in following configuration:

Pentium Core I5-2430M CPU @ 2.40 GHz
4GB RAM
64-bit Operating System
Matlab Platform

B. Simulation Environment

MATLAB stands for MATrix LABoratory, which is a programming package exclusively designed for speedy and effortless logical calculations and Input/output. It has factually hundreds of inbuilt functions for a large form of computations and plenty of toolboxes designed for specific analysis disciplines, as well as statistics, optimization, solution of partial differential equations, information analysis.

In this research work MATLAB platform is used to show the implementation or simulation of implemented algorithm performance. Measurement toolboxes are used and some inbuilt functions for generating graphs are used. Simulation results and comparison of the performance of implemented model with some existing ones are calculated by MATLAB functions.

The work here has presented a novel adaptive neural PSO switching of grid dynamics controller in hybrid power system design for damping electromechanical modes of oscillation and enhancing power system synchronous stability. The controlling algorithm comprises a front-end conventional analog IGBT based controller design, a adaptive PSO based optimizer and an artificial neural network (ANN) based stabilizing method, The work has done a comparative analysis of the three methodologies on driving the grid dynamics controller and its effects on power system being a) programmable hysteresis switching control b) Particle Swarm Optimization switching PWM modulation c) adaptive neural PSO switching.

The result has discussed outputs from the hybrid system in the following mentioned cases:

CASE 1: Hybrid system without grid dynamics controller

CASE 2: Hybrid system integrated with 9 bus systems with grid dynamics controller having programmable hysteresis switching control

CASE 3: Hybrid system integrated with 9 bus system with Particle Swarm Optimization switching PWM generation of grid dynamics controller

CASE 4: Hybrid system integrated with the 9 bus system having adaptive neural PSO switching of grid dynamics controller

The distortion level in the voltage as well as current output from the system by using various types of controlling algorithms of grid dynamics controller before its integration with two machine based power system is being analyzed. The comparative analysis of the power system stability is also done by comparing the rotor angle stability of the machines.

C. CASE 1: Hybrid system without grid dynamics controller

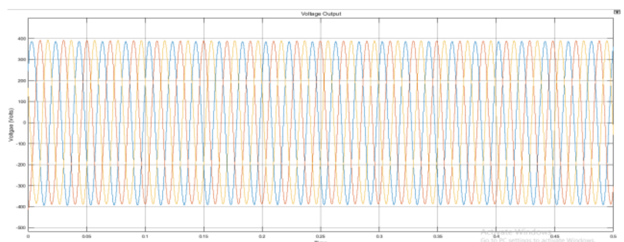

Fig. 12 Voltage output from the system without grid dynamics controller

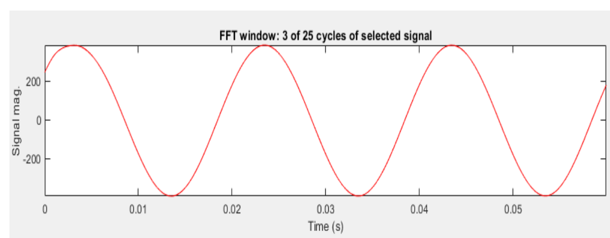

Fig. 13 FFT analysis of Voltage output from the system without grid dynamics controller

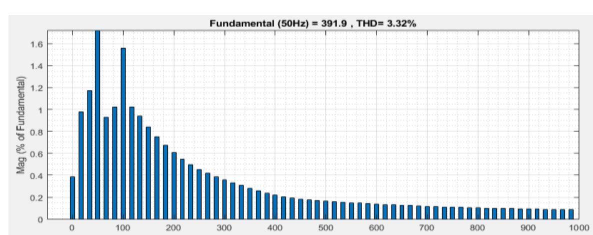

Fig. 14 THD % in Voltage output from the system without grid dynamics controller

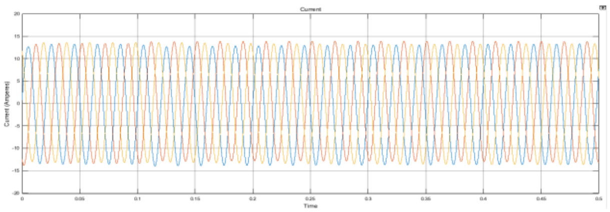

Fig. 15 Current output from the system without grid dynamics controller

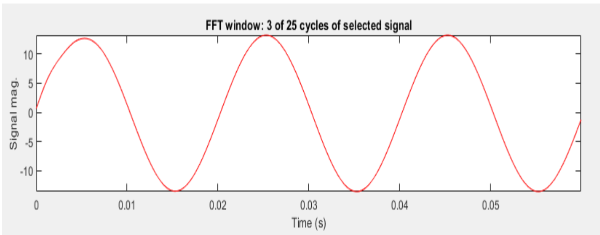

Fig. 16 FFT analysis of Current output from the system without grid dynamics controller

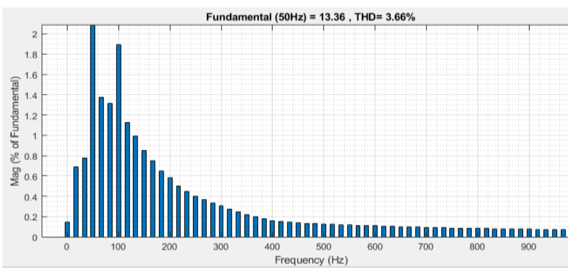

Fig. 17 THD% in Current output from the system without grid dynamics controller

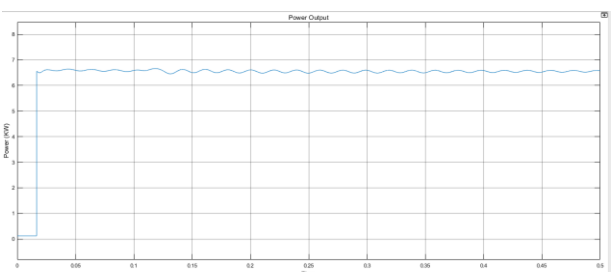

Fig. 18 Power output from the hybrid system without grid dynamics controller

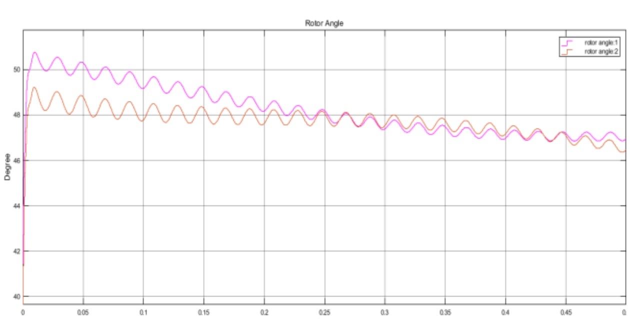

Fig. 19 Stability in system without stabilizer grid dynamics controller

D. CASE 2: Hybrid system integrated with 9 bus systems with grid dynamics controller having programmable hysteresis switching control

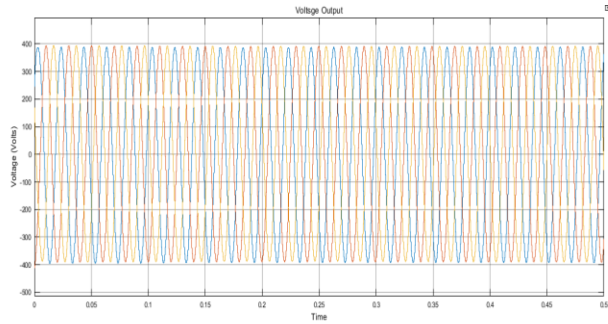

Fig. 20 Voltage output from the system with grid dynamics controller having programmable hysteresis switching control

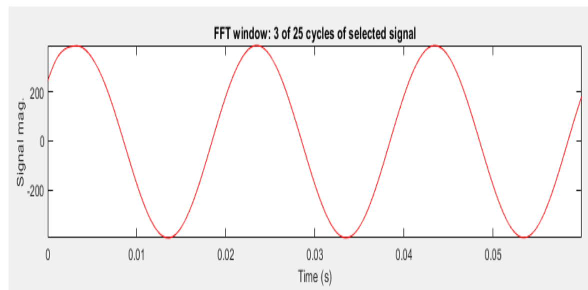

Fig. 21 FFT analysis of Voltage output from the system having programmable hysteresis switching control

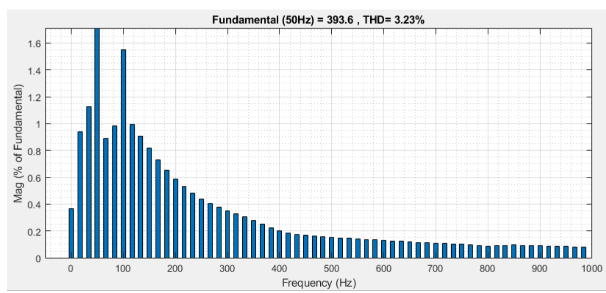

Fig. 22 THD% in Voltage output from the system having programmable hysteresis switching control

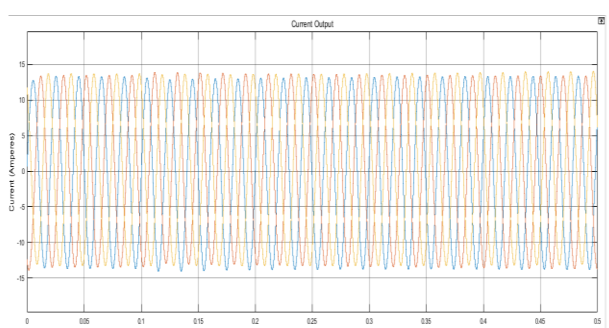

Fig. 23 Current output from the system with grid dynamics controller having programmable hysteresis switching control

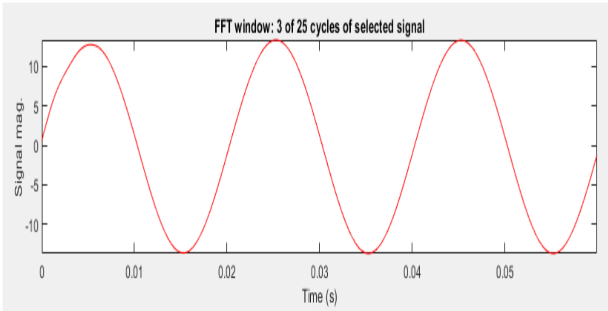

Fig. 24 FFT analysis of current output from the system having programmable hysteresis switching control

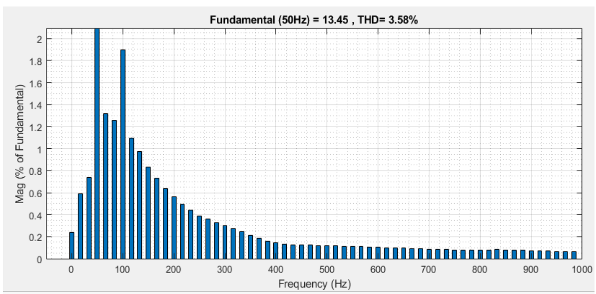

Fig. 25 THD% in current output from the system having programmable hysteresis switching control

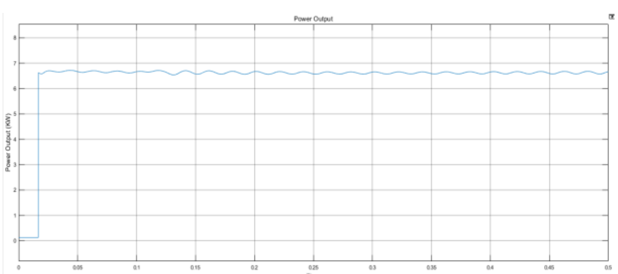

Fig. 26 Power output from the system having programmable hysteresis switching control

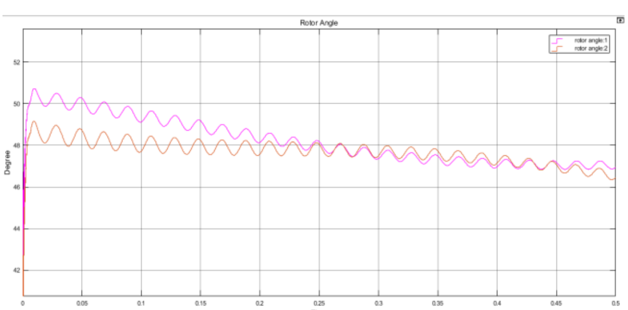

Fig. 27 Stability in system having programmable hysteresis switching control

E. CASE 3: Hybrid system integrated with 9 bus system with Particle Swarm Optimization switching PWM generation of grid dynamics controller

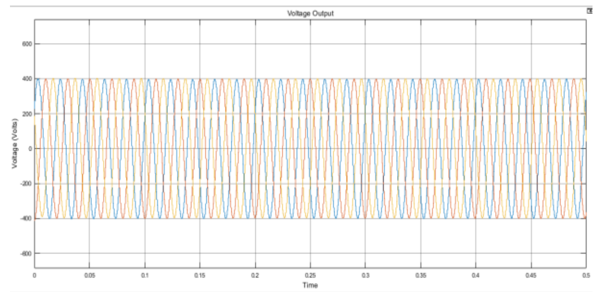

Fig. 28 Voltage output from the system with PSO switching PWM generation of grid dynamics controller

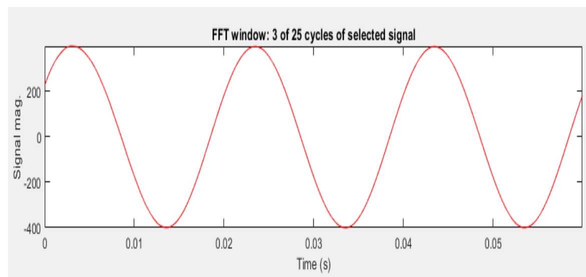

Fig. 29 FFT analysis of voltage output from the system with PSO switching PWM generation

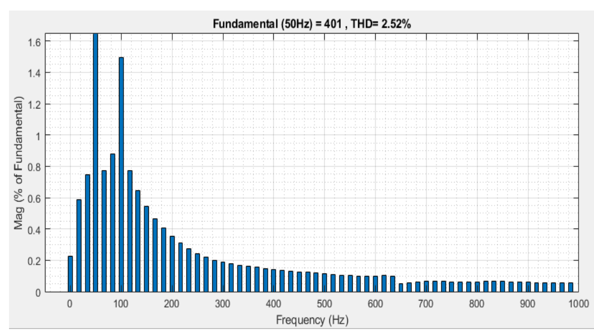

Fig. 30 THD% in Voltage output from the system with PSO switching PWM generation

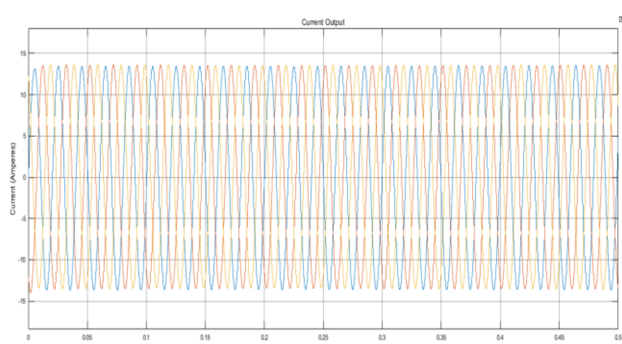

Fig. 31 Current output from the system with PSO switching PWM generation of grid dynamics controller

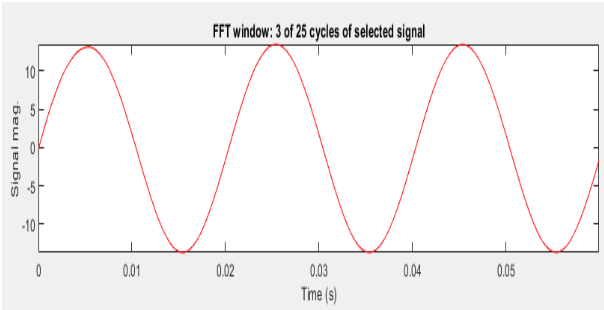

Fig. 32 FFT analysis of Current output from the system with PSO switching PWM generation

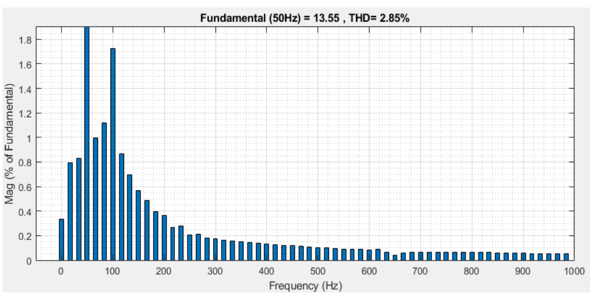

Fig. 33 THD% in Current output from the system with PSO switching PWM generation

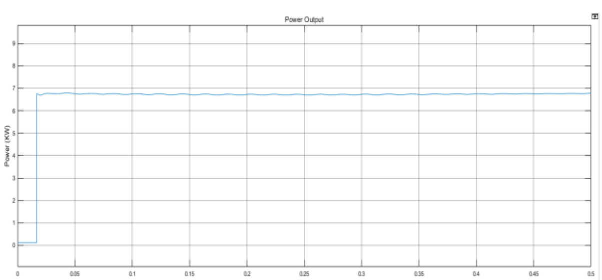

Fig. 34 Power output from the system with PSO switching PWM generation of grid dynamics controller

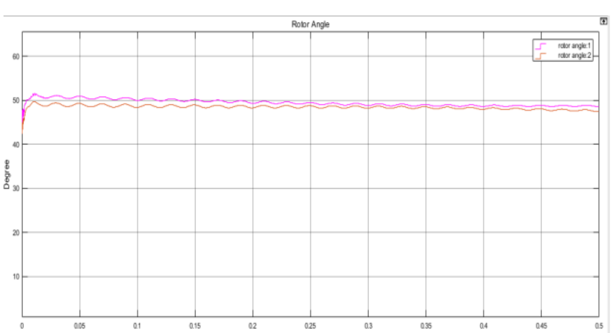

Fig. 35 Stability in system with PSO switching PWM generation of grid dynamics controller

F. CASE 4: Hybrid system integrated with the 9 bus system having adaptive neural PSO switching of grid dynamics controller

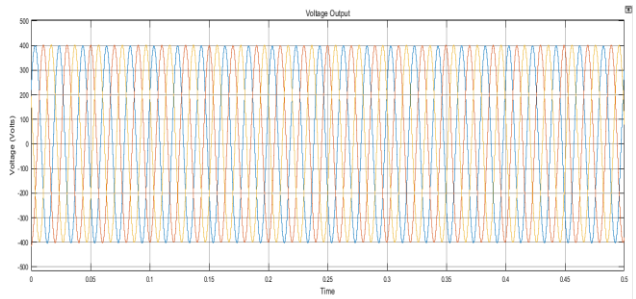

Fig. 36 Voltage output from the system with adaptive neural PSO switching of grid dynamics controller

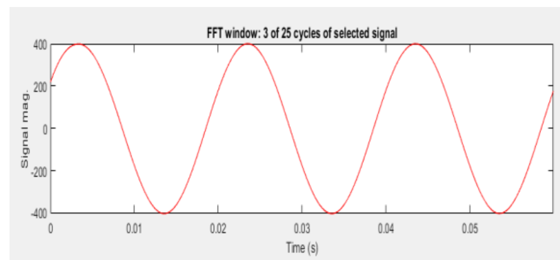

Fig. 37 FFT analysis of Voltage output from the system with adaptive neural PSO switching

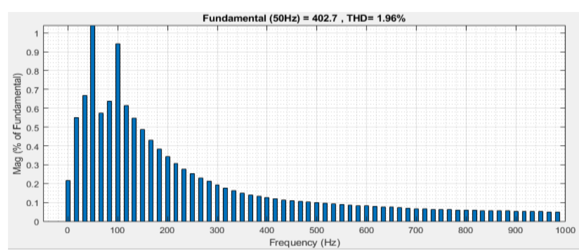

Fig. 38 THD% in Voltage output from the system with adaptive neural PSO switching

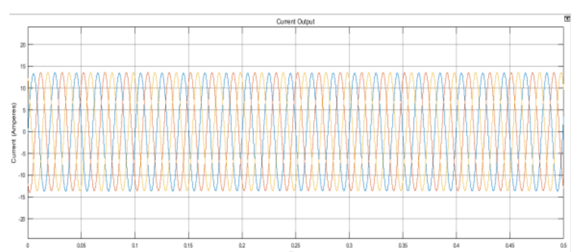

Fig. 39 Current output from the system having adaptive neural PSO switching of grid dynamics controller

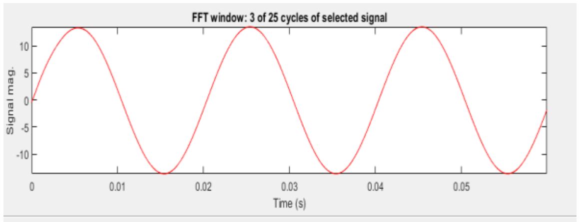

Fig. 40 FFT analysis of current output from the system with adaptive neural PSO switching

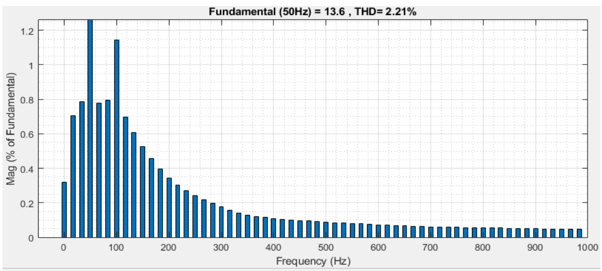

Fig. 41 THD% in current output from the system with adaptive neural PSO switching

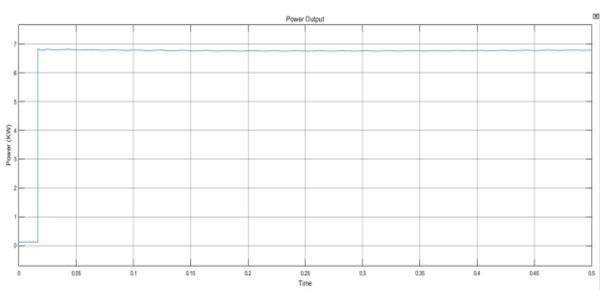

Fig. 42 Active power output from the system having adaptive neural PSO switching of grid dynamics controller

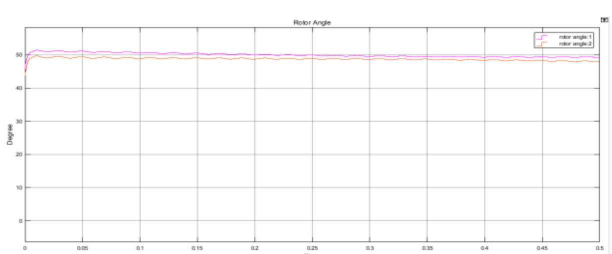

Fig. 43 Stability in system with adaptive neural PSO switching of grid dynamics controller

G. *Validation*

In his work a solar/wind based hybrid generation system has been developed in matlab/simulink environment. The two are the renewableenergy resources having variable input irradiation and wind speed parameters.

Table 3: Comparitive values of the output parameters from the systems with various controlling algorithms

Controlling techniques in grid dynamics controller	THD% in voltage	THD% in current	Power outputs (KW)
System without grid dynamics controller	3.32%	3.66%	6.576
programmable hysteresis switching control	3.23%	3.58%	6.668
PSO switching PWM controlling	2.52%	2.85%	6.785
adaptive neural PSO switching	1.96%	2.21%	6.792

The two systems when integrated with the 9 bus two machine grid system may lead to changes in the system output parameters and machine rotor angle stability in due to variable power outouts from the renewable energy resources. The system is therefore studied for the system dynamics and a controller is developed making use of different controlling techniques. The grid dynamics controller is developed having IGBT based bridge structure for controlling the systemstability and distortion levels.

Table shows the THD levels in the voltage and current output using various algorithms it was concluded that the distortion level in the power system having grid dynamics controller with adaptive neural network control was found to be least. It was found that the system with no controller was having maximum distortion levels in current as well as voltage waveforms. The power improvement was also seen reducing the losses in the system by serving stable input to the grid energy system.

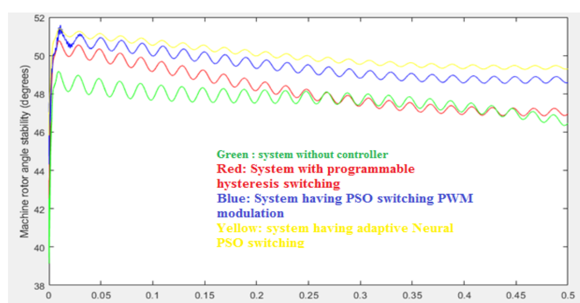

Fig. 44 Comparative analysis of Rotor angle stability in different cases

Red describes the rotor angle stability in basic system without controller, green describes the rotor angle stability in machines in the system with programmable hysteresis switching control of grid dynamics controller, blue describes the rotor angle stability in two machines system having PSO based PWM implementation with grid dynamics controller and yellow describes the rotor angle stability in machines in the grid dynamics controller with adaptive neural based PSO switching control. The graph depicts the effectiveness of the final hybrid algorithm in terms of stability.

VI. CONCLUSION

Power system stability is best defined as the ability of an electric power system to regain a state of operating equilibrium after being subjected to a physical disturbance, when variables are bounded so that practically the entire system remains intact. The renewable energy resources are the future of the world electrification that are viable to produce electricity from variable input parameters like variable irradiation levels in solar system and variable wind speed in wind energy systems. These systems when integrated with grid require proper regulation of the electrical parameters to avoid and constraints and misbalances in the grid system.

In order to demystify the complexity of the integrated approach, the work first presents the basic concepts, and then explores a simulation test bed in MATLAB in order to use these concepts to solve a basic problem in the development of two machine based grid energy system. Acquiring overall stability in the system stays the key concern to which s grid dynamics controller has been developed and a comparative analysis has been carried out by driving the same with different switching approaches including the AI based optimization techniques. The basic idea about control for three-legged IGBT based grid dynamics controller was discussed in detail. Then the mathematical model of the problems arrived while grid integration of renewable energy based sources is formulated, and the solution steps are outlined.

The following main conclusions were carried out:

- THD % of voltage in the system having no controller was found to be 3.32 % and in the system having adaptive neural PSO switching of grid dynamics controller the distortion level came down to 1.96%
- The hybrid system with solar wind energy was further integrated with grid and was analyzed for the rotor angle stability in the two machines. It was concluded that out of the three controls for grid dynamics controller the artificial intelligence based adaptive neural PSO switching was found to be best with maximum stability of machines.
- The power delivered with the artificial intelligence based adaptive neural PSO switching control of grid dynamics controller in hybrid PV system is 6.792 KW
- The efficiency of system is thus enhanced by making the model better in quality and improved rotor angle stability in the machines

The above conclusions depict the efficiency of the work and hence make the system suitable for driving any kind of loads in the system having renewable energy based integration

A. *Future work*

A Power System with grid dynamics controller which is installed with the renewable energy based grid integration can improve power system stability. The grid dynamics controller has excellent cost performance compared to other power system modifications or additions. The work can be further enhanced to analyze the AI based technology for prediction of instability in the system using data at the load side consumption. Analysis of such condition will predict the voltage instability in the system. Grid dynamics controller to remove the voltage instability can be designed to make the power grid free from effects of loading also.

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