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Analysis of Stability in Power System by Designing Two Area Four Machines System

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Abstract: *An electrical power grid is a system of connected substations that distributes creates electricity to customers. The position of power plants is driven by the accessibility of fuel, the place of a dam, or an effective placement for renewable energy sources. As a result, they are frequently found far from populated areas. That's very feasible because transmitting electrical power over longer distances is much more cost effective than transmitting any other fuel. After a disturbance, a system's voltage stability refers to its ability to restore a steady-state voltage of acceptable magnitude. Thereby, in this work, we are trying to design a two-area, four-machine system in the MATLAB/SIMULINK environment, which will be incorporated with a WES (wind energy system) to derive the experimental setup under investigation.*

Keywords: Renewable Energy, Power Grid, Power Quality, DFIG, Voltage Stability, STATCOM, NN, THD

I. Introduction

Renewable energy is energy generated from naturally refilled and non-depleting sources such as the sun as well as wind. Renewable energy can be used to generate electricity [1], heat as well as cool space or even water [2], and transport [3]. RES (Renewable energy sources), including biomass, geothermal resources, solar radiation, water, & wind, are renewable resource which can be transformed into hygienic, useful energy, including wind, solar, bioenergy, hydro energy, and oceanic energy. Renewable energy has substantial advantages that impact the economy, the environment, national security, and people's health.

Power production, transmitting, and allocation are the three main functions of electric grids. The initial stage in providing electricity is power production, which is done at a power station (coal, nuclear, geothermal, hydro, and so on). The second [4] stage in distributing electricity is power transferring, which facilitates the transfer of electricity from power stations to power companies' distribution networks. At last, by distributing utility grid, power distribution fulfills the electric grid's functions[5]. Power transmission uses architecture that can manage high voltage (110+ kV), so even though power distribution uses facilities that can manage medium (50 kV) and low (1 kV) voltage.

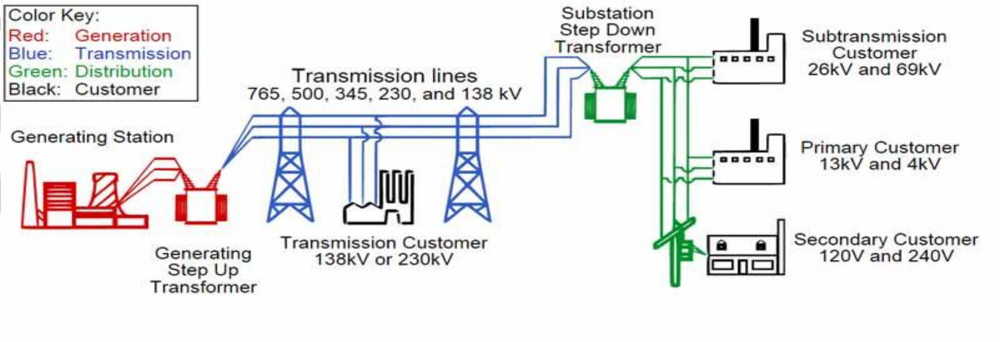

Figure 1: Typical Layout of an Electrical Power Grid

Power production, transmitting, and allocation are the three phases of a power grid. Every one of these phases is described in greater depth further down.

The power electronic functionality regulates the rotor currents in the doubly-fed induction generator (DFIG) [6] system, that also achieves the speed control required for optimum storing energy in varying winds. The DFIG combines the benefit of variable speed controlling with lowered cost and power losses since the power electronics hardly handle the rotor power, which is generally just under 25% of the as a whole output power.

A Doubly Fed Induction Generator is a three-phase induction power source with three-phase AC signal fed to both the stator windings and rotor windings. Multi stage windings are installed upon both rotor and stator bodies. It also includes a multi stage slip ring gathering for power transmission to the rotor. It is commonly used in wind power generation to produce electricity.

After a disruption, a system's voltage stability relates to the ability to reinstate a steady-state voltage of appropriate magnitude. Because most household loads are inductive, they cause a phase shift in transmission systems, resulting in the notion of reactive power. At generation facilities, voltage can be controlled by AVRs, that also leads to a change in the generator's vibrational winding, impacting reactive power implicitly. Voltage regulation nearer to a functionality is

favoured because it accounts for transmission line shortfalls. Tap-changing transformers in transmission system, capacitor banks, static VAR compensators (SVCs), as well as STATCOMs for reactive power compensation are used to accomplish this [7].
STATCOM, or Static Synchronous Compensator, is a power electronic instrument that utilizes force commutated gadgets such as IGBTs, GTOs, and other force commutated gadgets to regulate the reactive power circulation across a[8] power system, thus also improving the network's stability. STATCOM is a shunt device, which means it is attached to the line in a shunt configuration. A Static Synchronous Condenser (STATCOM) is another name for a Static Synchronous Compensator (STATCOM) (STATCON). It belongs to the FACTS (Flexible AC Transmission System) family of devices. STATCOM's term Synchronous refers to its ability to absorb or generate reactive power in synchrony with demand in order to maintain the voltage level network [9].

II. LITERATURE REVIEW

(Eluri & Naik, 2021)[10] This paper specifies conceptual viewpoints on RES, unconventional energy sources as well as integration, upcoming problems for "Renewable energy sources (RES)" and techniques for attempting to control various types of microgrids. Because of their periodic nature, the significance of RES has grown in the electrical power system. If the need for Energy Management Systems (EMS) arises, its production does not correlate with the load point. Energy management (EM) is a term used in this lexicon to describe a formidable problem in the operating condition of distributed renewable energy sources that are connected to the power grid. The difficulty in this type of source stems from factors including rare sources, time of day estimations, the surface area of the "solar panels," "battery," charging and discharging speeds of the battery, and the dimensions of the "solar panels," "battery." The contribution of this research is that it presents the most recent scenarios, as well as the prospects of solar and wind energy in India, in a graphical format, and discusses control methods and microgrid optimization methods in depth. The fundamentals of microgrid, obstacles in grid integration, optimization methods, and the notion of "Distributed Energy Resources (DER)'s" are discussed in this section.

(Transactions & Electronics, 2017)[11]A simple plug-and-play voltage Ripple Mitigator (RM) is suggested in this study. Unlike other approaches to reducing voltage ripple, the project were discussed can be connected to the DC link of a hybrid AC-DC power system without requiring any changes to the host system. To accomplish plug-and-play procedure, a local bus-voltage control method is used in general and especially. This device can be used as a standalone module if only the DC-link voltage monitoring is required. The efficiency of the ripple-mitigating function, the hot-swap operation, and the non-intrusive assets of the RM have been validated experimentally through conceptual analysis and research collaborate on a boost-type PFC rectification system.To illustrate most of the functions of the RM, outcomes from a 110W miniaturised hybrid AC-DC power system with an AC/DC converter and two resistive loads are involved.

(Akbari et al., 2021)[12] Presents a new WECS premised on a doubly-fed induction generator (DFIG) that uses only a reduced-size rotor side converter (RSC) in conjunction with a supercapacitor. The grid side converter (GSC) used in traditional DFIG-based WECSs is effectively removed in the proposed architecture. The hydraulic transmission system (HTS) is often used as a consistently variable as well as shaft decoupling transmission medium to achieve this. This revolutionises traditional constant-ratio drives by allowing users to manage the power flow again through generator's rotor circuit regardless of the shaft speed of the wind turbine. Without using GSC, this characteristic of HTS can be used to control the RSC power and, as a result, regulate the supercapacitor voltage.To confirm the findings and prove the system's dynamic response, the present scheme is explored and modelled in MATLAB Simulink at different wind speeds.

(Wei et al., 2021)[13]A coordinated DC-link voltage control (CDVC) scheme is suggested to improve the HVRT achievement of offshore doubly-fed induction generator (DFIG) wind turbines integrated with the supercapacitor energy storage system to deal with DC-link overvoltage throughout high-voltage ride-through (HVRT) (SESS). This arrangement is developed as a two-stage control problem based on the depth of grid voltage swell, which can protect the converter from damage caused by insufficient reactive support in the first stage and achieve efficient coordinated control under a variety of grid voltage swell magnitudes and timescales. In the first phase, a voltage-dependent reactive current control (VRCC) plan is developed to control the wind turbine's current reference, taking into account the DFIG's dynamic behaviour during HVRT. The primary goal of the first stage is to provide fast reactive current support without the use of a DC chopper. Once the DC-link voltage exceeds a predetermined threshold, a synchronised control scheme involving the SESS as well as wind turbine operation is incorporated in the second phase, with the goal of regulating excessive active power by monitoring the current reference from the first stage.

(Schaab et al., 2017)[14]This paper, on the other hand, proposes a scheme for unified controller synthesis that addresses rotor angle stability and voltage stability simultaneously for grids with synchronous generators and wind energy conversion systems with doubly-fed induction generators. First, a method has been proposed for describing generating units using linear-parameter-variable (LPV) systems, in which grid or wind variation are mapped into time-varying model parameters. Distributed robust controllers can be synthesised using semidefinite programming for appropriate ranges of these parameters, allowing the power grid to be stabilised for the considered variations as well as disruptions.

The approach's efficiency is evidenced for a multi-bus benchmark system with well-damped grid oscillations and an LPV-controller that stabilises the grid after permanent changes.

(Systems et al., n.d.)[15]Utility-scale converters in photovoltaic (PV) power plants were disconnected due to transmission faults caused by recent wildfires in California. Tripping commands were caused by phase-locked loops (PLLs) and dc-side dynamics, which are typically un-modeled in classical transient stability studies, according to postmortem investigations. Because existing design packages rely on simplified models that ignore these dynamics, they can only predict converter behaviour during faults to a limited extent. To address this failings, we developed a positive-sequence model for PV power plants based on first-principles physics as well as controls. The model includes PLLs, dc-side dynamics, and closed-loop controllers, as seen on utility-scale three-phase converters. The established model is implemented in illustrative power systems with generating units. A collection of stability and performance metrics are used to evaluate numerical simulations of the procured multi-machine multi-converter power systems.

(Morshed, 2020)[16] presents a novel framework for coordinating the controllers of doubly fed induction generators (DFIGs) and synchronous generators at the same time (SGs). The envisaged coordination method is based on the zero dynamics method, and it aims to improve the transient stability of multi-machine power systems underneath a variety of conditions. IEEE 39-bus power systems were used to test the proposed method. The performance evaluation took into account the transient stability margin, which was measured in terms of critical clearing time, as well as eigenvalue analysis and time domain simulations. The values obtained were also assessed using a traditional power system stabilizer/power oscillation (PSS/POD) technique and a passivity-based controller for connectedness and damping assignment (IDA-PBC).The suggested approach's capabilities to enhance damping and the system's transient stability margin underneath a various operating conditions was confirmed by the performance monitoring.

(Ghanasyam et al., 2018) [17]suggested a new method to enhance the transient stability of a multi-machine power system that incorporates hybrid renewables. The goal of the research is to examine the system's transient response with consistent and differing power infusion from a DFIG-based wind farm and a solar photovoltaic (PV) farm. The converter controllers in the DFIG and Solar PV systems have been designed in such a manner that both renewable sources enable higher reactive power injection during fault periods, unlike during normal periods. The bus voltage magnitude improves as a result of this coordinated reactive power support throughout a fault, which effectively improves system transient stability. Faults are analyzed in various load buses, and the stability of the cases with and without the proposed controller is especially in comparison. The research is conducted in a WSCC 3-machine 9-bus system, with PSCAD/EMTDC as the simulation environment.

(Honghai et al., 2009)[18]With the world's energy crisis worsening and pollution levels rising, distributed generation (DG) relying on renewable energy has emerged as an emerging trends for the electric power sector in the twenty-first century. However, because DG is impacted by natural conditions and is unable to produce power consistently and steadily, large-scale wind turbine generators fully integrated into the grid will have an effect on the sustainability of the electric power system. A super capacitor energy storage system (SCESS) superior to certain other energy storage systems and a doubly fed induction wind generator are discussed in this work to make sure stable operation of the electric power system. SCESS is fed to the network at the point of common coupling. For simulation and experimental analysis, Matlab/Simulink software is used. This paper focuses on the transient stability problem. Simulation results demonstrate that SCESS can enhance transient stability of multi-machine wind turbine generators mechanisms grid - connected, whereas using doubly fed induction generators can also enhance electric power system stability.

(Kanchanaharuthai et al., 2014)[19]The use of STATCOM and BESS to improve the transient stability of large-scale multimachine power systems with synchronous as well as doubly-fed induction generators is investigated in this paper (DFIGs). The performance of a two-area system comprised of two synchronous generators (SGs) and two DFIG, as well as a STATCOM/battery energy storage system, is assessed using a passivity-based control development methodology [interconnection and damping assignment passivity-based control (IDA-PBC)]. The main objectives of this study are threefold:1) illustrating the implementation of nonlinear control hypothesis (specifically the IDA-PBC methodology) for the architecture of a stabilising feedback controller in large-scale power systems to enhance transient performance of a system; 2) establishing a research methods that can use the additional degrees of freedom in large-scale power systems for improving transient system performance; and 3) working to develop a technique that can use the additional degrees of freedom in large-scale power systems for improving transient performance of the system.

III. MODLEING TWO AREA SYSTEM

We incorporated various renewable energy resources as well as examined the impact of the integration on the grid comprising two area 4 machine system in order to analyse the grid's stability. The kundur two-area system is used as the prototype system, with a) wind energy incorporation, b) solar/wind hybrid interconnection, and c) solar/wind/fuel cell integration being tested. The test system has been entirely altered to include three renewable energy power generation networks. After incorporation, the machine's as well as generation points' consistency is investigated.

The impacts appeared to be excessive in comparison to the reasonable parameters, so a dynamic system optimising controller was designed using feed forward neural learning of the system dynamics to achieve stable system response in all facets.

The selected test system consists of two areas with four machines each. The system is linked to the highly varying wind energy source that feeds it. The system is depicted in a single line diagram as shown in figure.

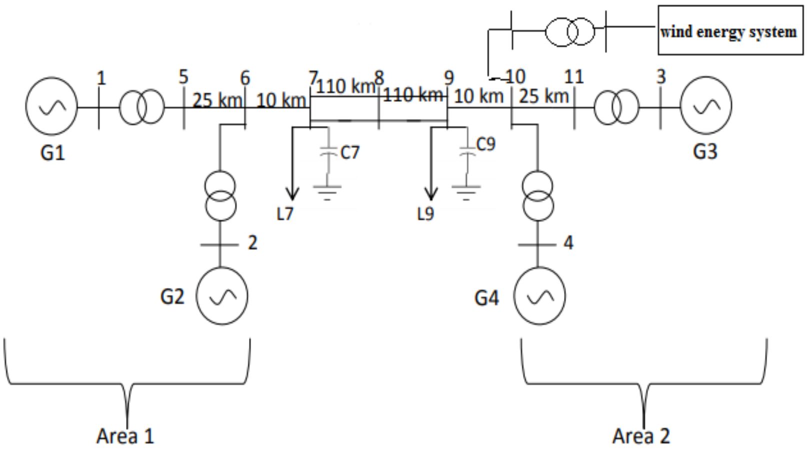

Figure 2: Single line diagram of two area system on wind integration

On 900 MVA and 20/230 kV, so every step-up transformer has an impedance of 0+j0.15 per unit and an off-nominal ratio of 1.0. The nominal voltage of the transmission system is 230 kV. Figure 2 shows the lengths of the lines. The line variables in per unit on a 100 MVA, 230 kV basis are as follows:

Table.1 : Transmission line parameters in two area system	
r	0.001 pu/km
x_L	0.001 pu/km
b_c	0.00175 pu/km

Area 1 is supposed to export 400 MW to area 2, and the system is supposed to work. Incorporation with a changeable energy resource, on the other hand, results in some variability at the loading points. The following are the loads and reactive power supplied (QC) by the shunt capacitors at buses 7 and 9:

Table 2: Loading at the buses 9 and 7			
Bus	P_L	Q_L	Q_C
Bus 7	967 MW	100 MVAr	200 MVAr
Bus 9	1767 MW	100 MVAr	350 MVAr

Various modeling techniques are developed by researchers to model components of HRES. Performance of individual component is either modeled by deterministic or probabilistic approaches.

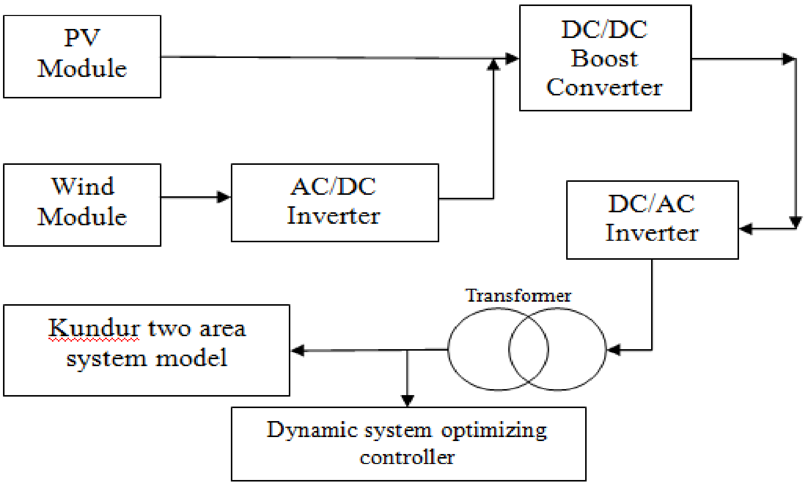

Figure 3: Proposed Hybrid energy system topology

IV. FEED FORWARD NEURAL LEARNING

This chapter will go over the various control strategies used with the controller to evaluate its effectiveness in terms of rotor angle stability, THD level assessment, and generation point stability when used in conjunction with variable renewable energy resources. The numerous block diagrams associated with the operation of a controller utilising neural-based learning of dynamic systems, as well as its control algorithms, are mentioned. The dynamic system optimization control flow chart is shown.

Feed forward Neural network based learning of system dynamics arriving at the integration

Artificial neural networks (ANNs) are information processing systems that mimic human behaviour. Even when our model has noise, ANNs obtain inherent data from the regarded functionalities and gain knowledge from the input data. The structure of an ANN is made up of essential information processing units called neurons.

They are divided into many layers and linked together by weights. The interaction between each pair of neurons is represented by synaptic weights. The information is distributed through into the neurons by these structures. Mixtures of different transmission functions are used to calculate the mappings of inputs as well as approximated output responses. The training algorithms of artificial neural networks can be analysed using the self-adaptive information pattern matching method of analysis.

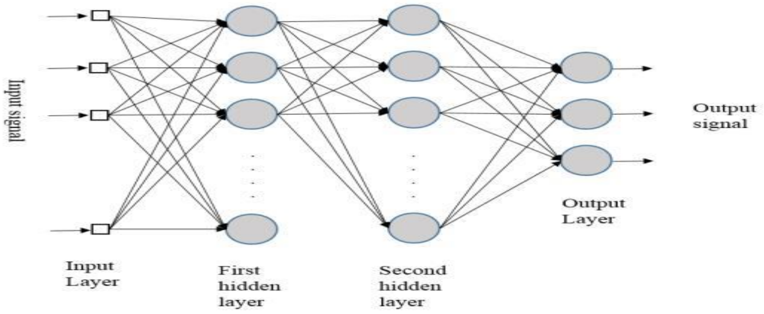

Figure 4: Architectural Graph of an MLP Network with Two Hidden Layers.

Single-layer perception (SLP) networks and multilayer perception (MLP) networks are two types of neural systems. Various levels of simple two-state sigmoid transfer functions with handling neurons that communicate by implementing weighted connections make up the multilayer perception network. The input layer, output layer, and hidden layer make up a typical feed-forward various approaches neural network. This study uses the multilayer perception (MLP) with the backpropagation neural learning algorithm because it has been used by many previous researchers and is also a generalised estimation.

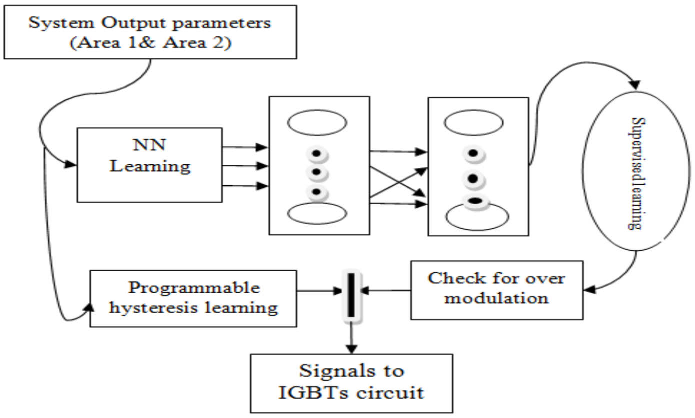

Figure 5: PSO – NN controller Technique implemented in MATLAB/SIMULINK

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 5. The function of this network was described as follows:

Y_j=f(∑w_ij X_ij) Eq(5)

whereYj 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. The development of the controller was attained with employing an IGBT based automatic switching of the bridge circuit with proper controlling optimizing algorithm for acquiring machine stability at the grid. The research of system oscillations is combined with the investigation of system electrical output variables, and a neural well trained to learn the system as efficiently as possible. The variations that occur when renewable energy resources are integrated are being researched and mitigated by sending signals to an IGBT-based bridge circuit that produces output to balance the disruptions. Figure 4.2 shows the flow chart for the system control used in the construction of the new dynamic systems control system. Hidden units with varying activation functions can be added incrementally as new hidden units are added. Even though sigmoidal activation functions are ideal for networks with binary outputs, this is not always the case for networks with continuous-valued outputs. Enabling new hidden units to have variable activation functions can result in smoother guesstimates, and also quicker learning with very few calculations and hidden units needed.

V. Results

The chapter has discussed the variations in the total harmonic distortion in the voltage and current waveforms, rotor angle deviations, power stability in p.u at generating points and rotor speed variations to study the effectiveness of the designed dynamic system optimization controller.

Case 1: Two area system with wind integration with STATCOM without any controller

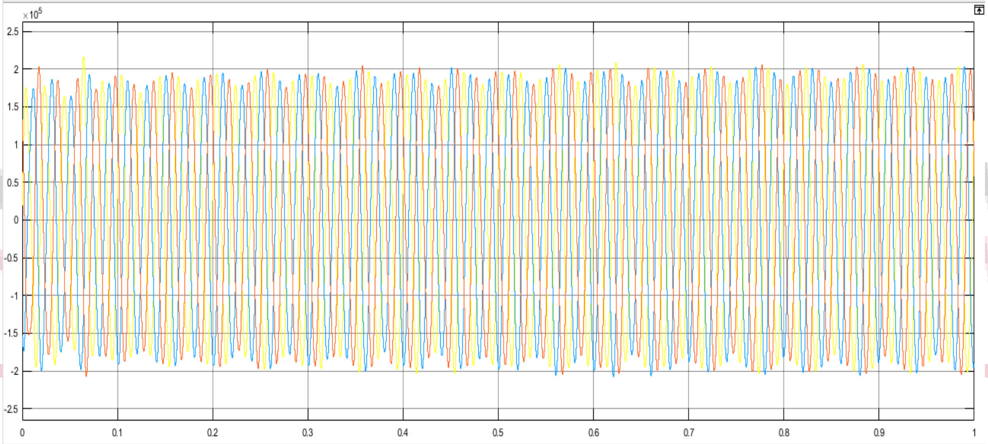

Figure 6: Voltage at the grid

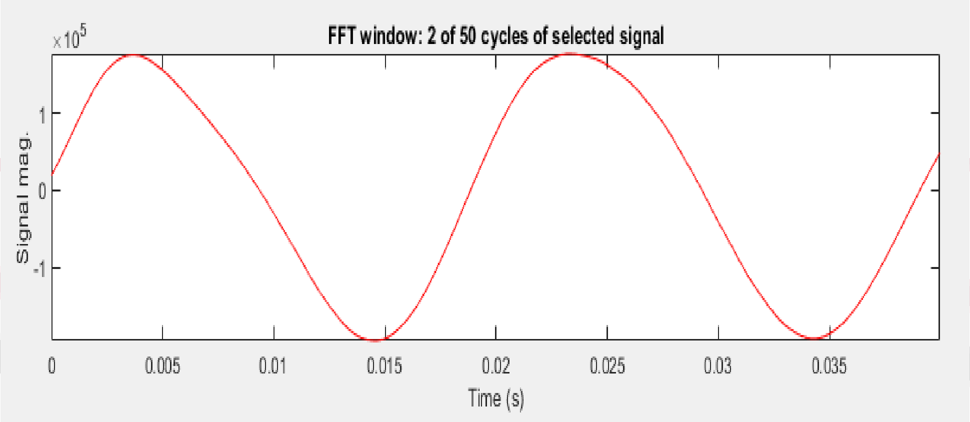

Figure 7: FFT analysis of voltage at the grid

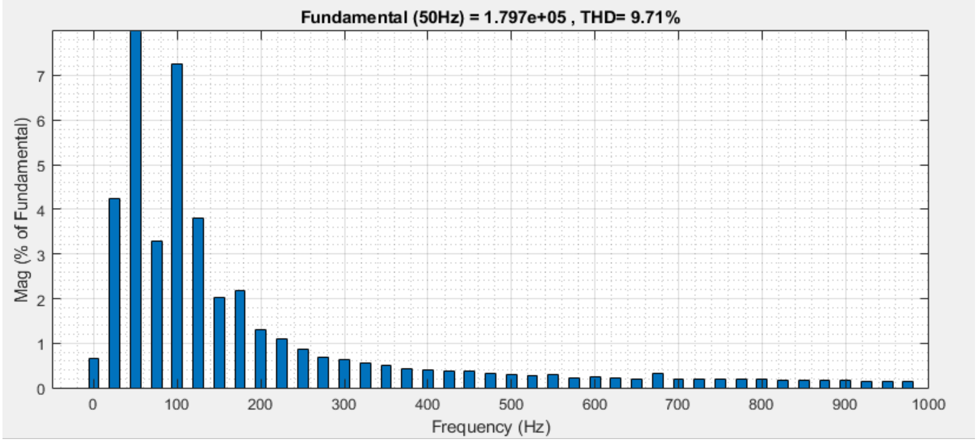

Figure 8: THD % in voltage at the grid

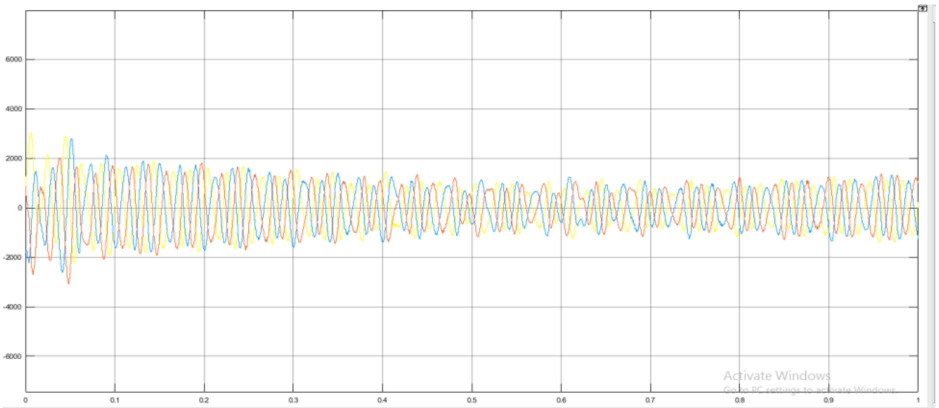

Figure 9: Current at the grid

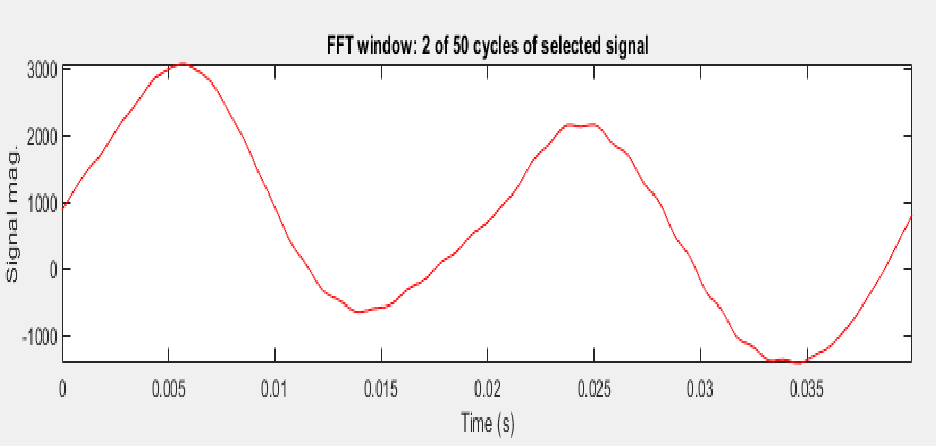

Figure 10: FFT analysis of current at the grid

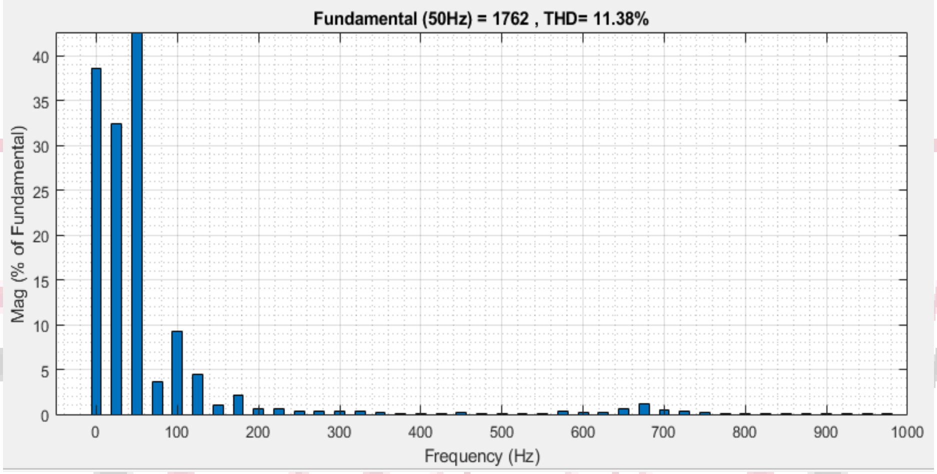

Figure 11: THD % in current at the grid

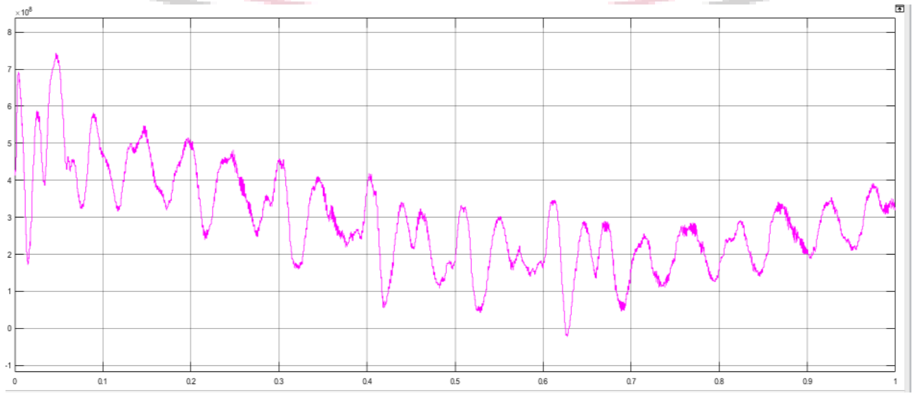

Figure 12: Active power at the grid

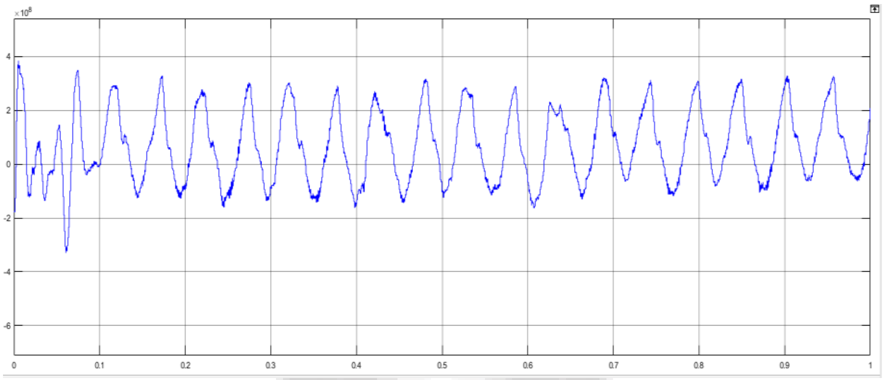

Figure 13: Reactive power at the grid

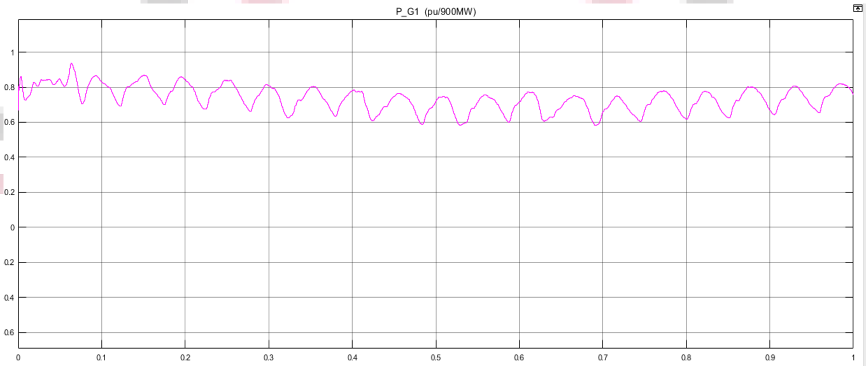

Figure 14: Power stability in p.u at the generating terminal of machines

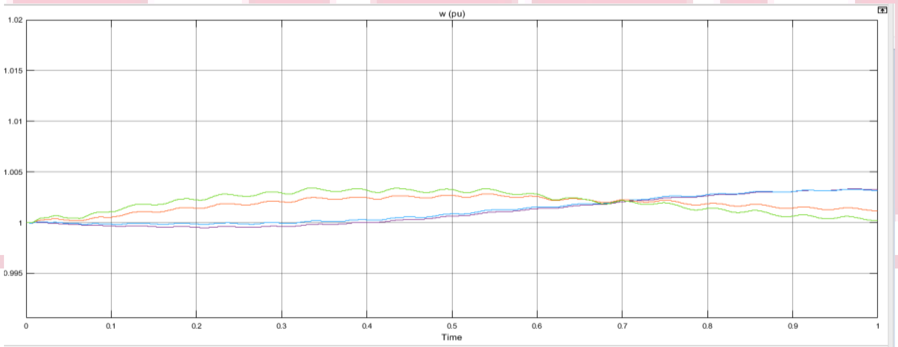

Figure 15: Rotor Speed variations on wind integration

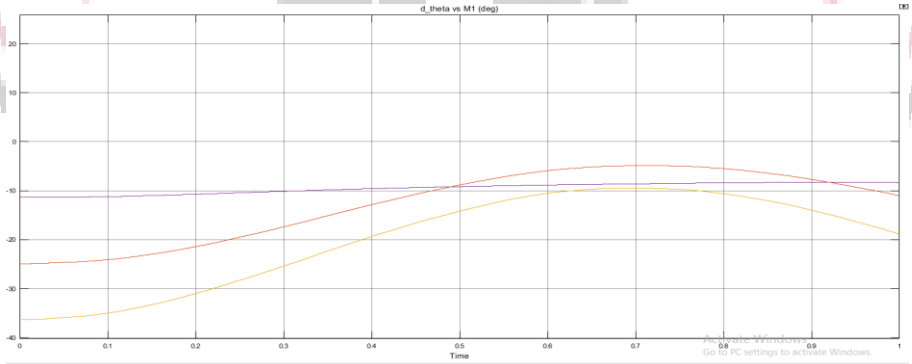

Figure 16: Rotor Angle Deviation at the machines on integration with wind energy resource

Case 2: Two area system with wind-solar integration and dynamic system optimizing control for system stability enhancement.

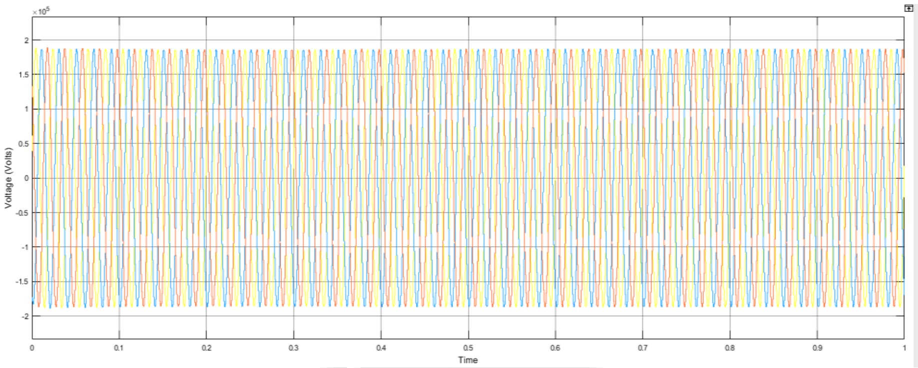

Figure 17: Voltage at the grid in two area wind-PV integrated system with Dynamic system optimization control

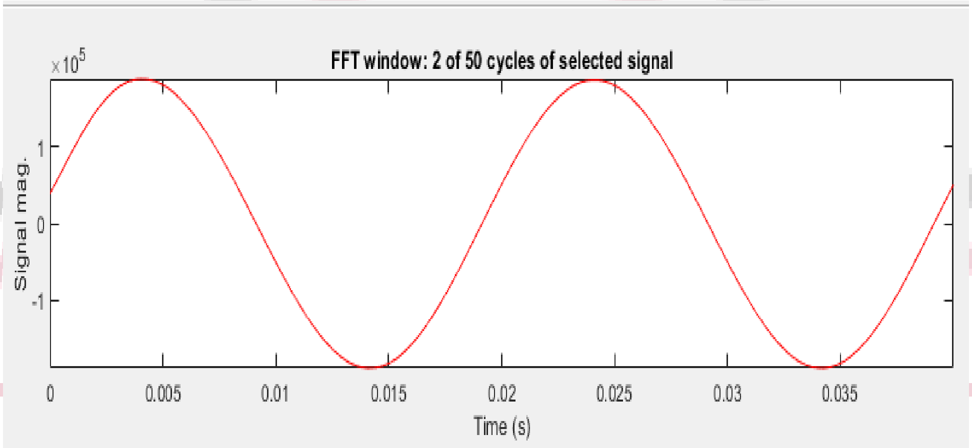

Figure 18: FFT Analysis of voltage at the grid

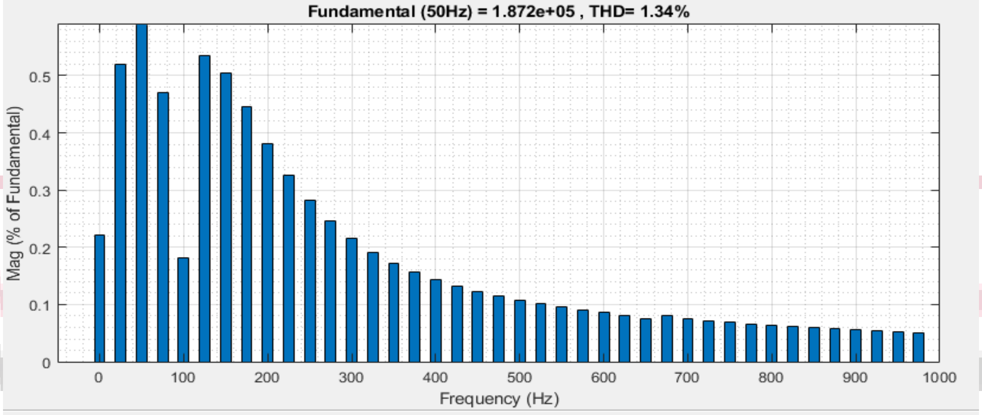

Figure 19: THD% in voltage at the grid

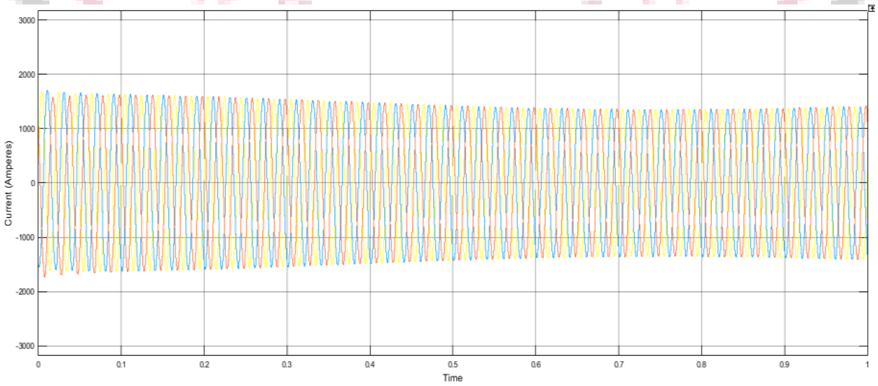

Figure 20: Current at the grid in two area wind-PV integrated system with Dynamic system optimization control

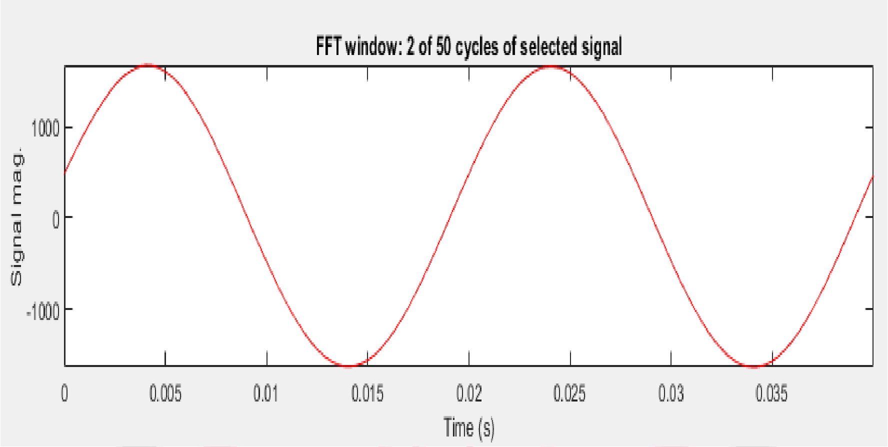

Figure 21: FFT Analysis of current at the grid

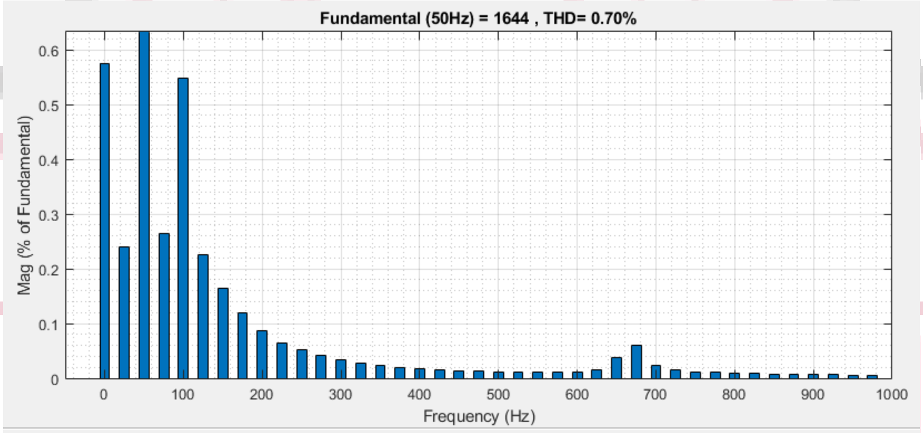

Figure 22: THD% in current at the grid

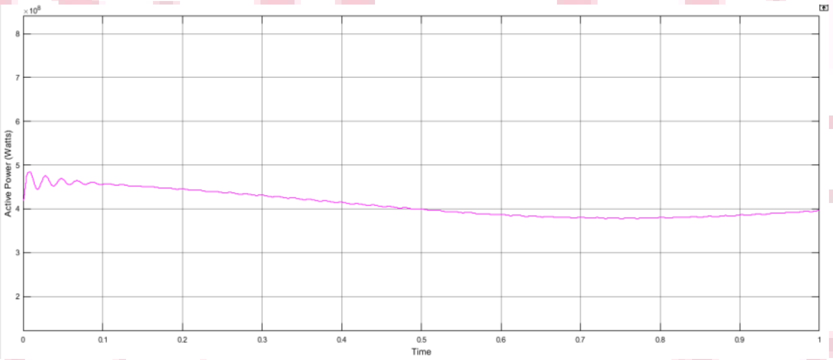

Figure 23: Active Power at the grid in two area wind-PV integrated system with Dynamic system optimization control

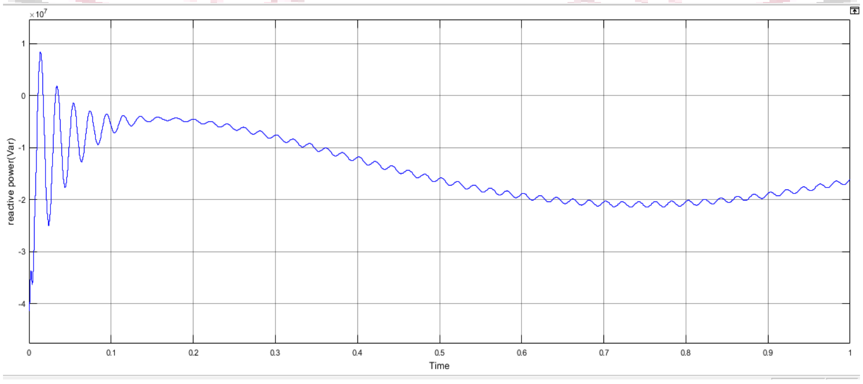

Figure 24: Reactive Power at the grid in two area wind-PV integrated system with Dynamic system optimization control

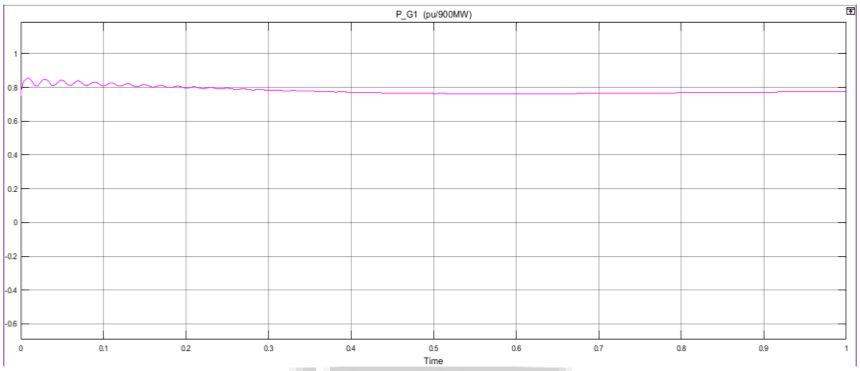

Figure 25: Power stability in p.u at the generating terminal of machines

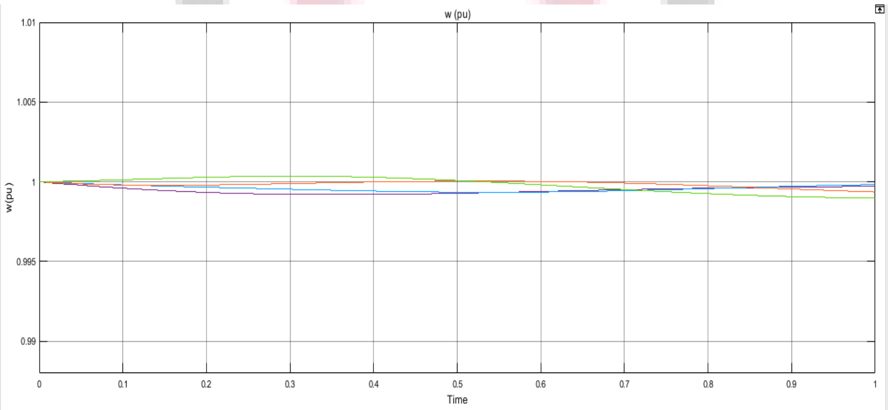

Figure 26: Rotor Speed variations on wind/Solar integration with Dynamic system optimization control

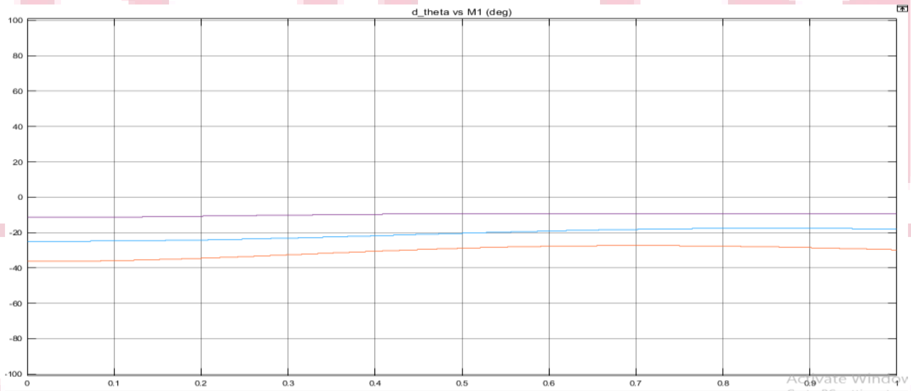

Figure 27: Rotor angle deviation in machines with wind/solar integration and controller

Case 3: Two area system with wind-solar and Fuel cell integration and dynamic system optimizing control for system stability enhancement.

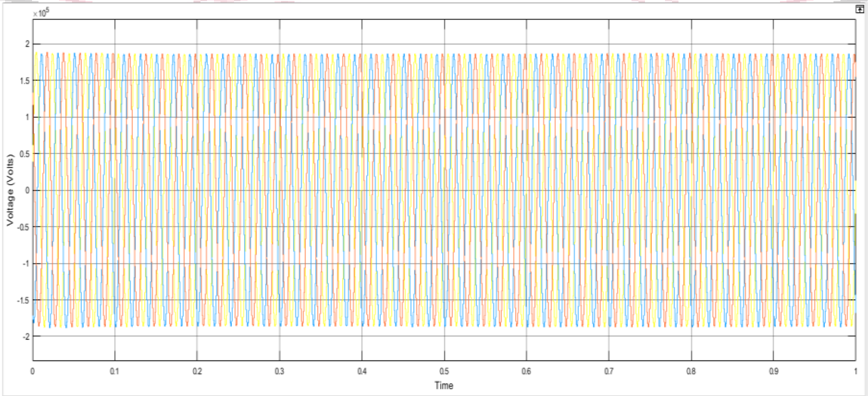

Figure 28: Voltage at the grid in two area wind-PV-FC integrated system with Dynamic system optimization control

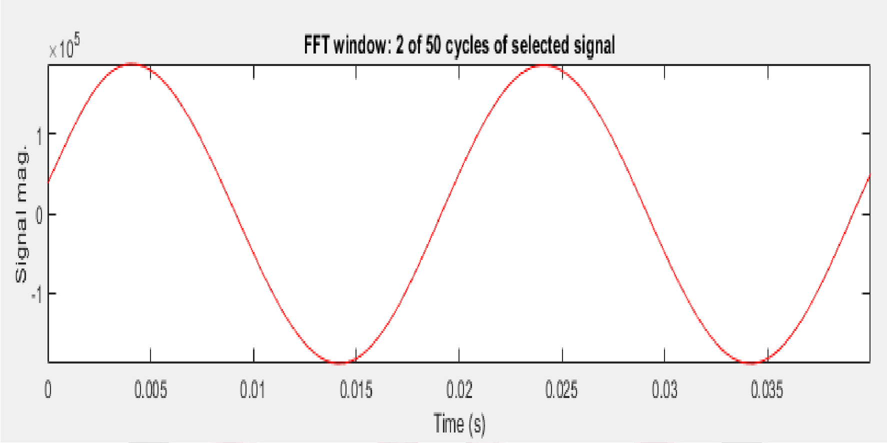

Figure 29: FFT Analysis of voltage at the grid

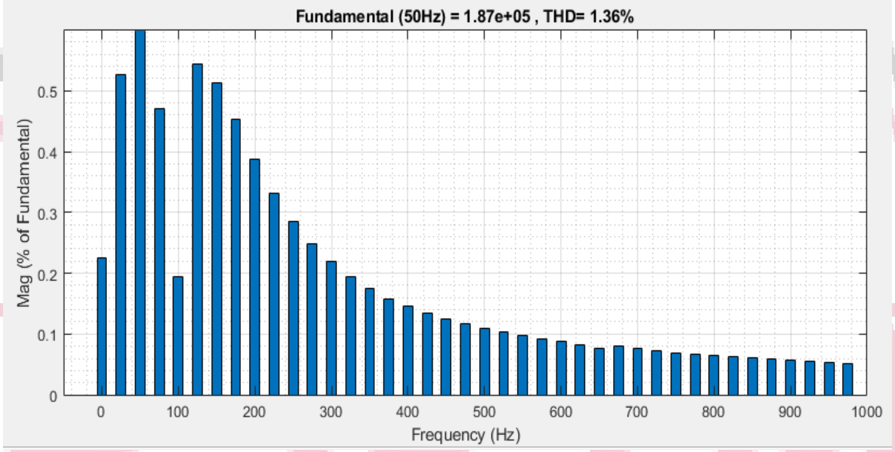

Figure 30: THD% in voltage at the grid

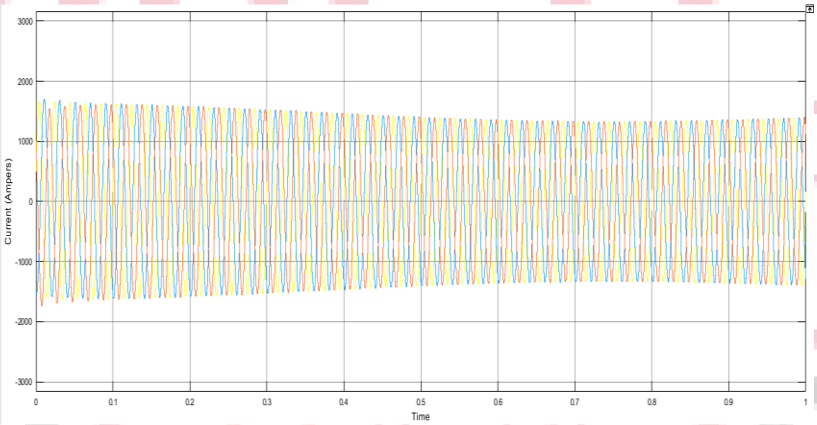

Figure 31: Current at the grid in two area wind-PV-FC integrated system with Dynamic system optimization control

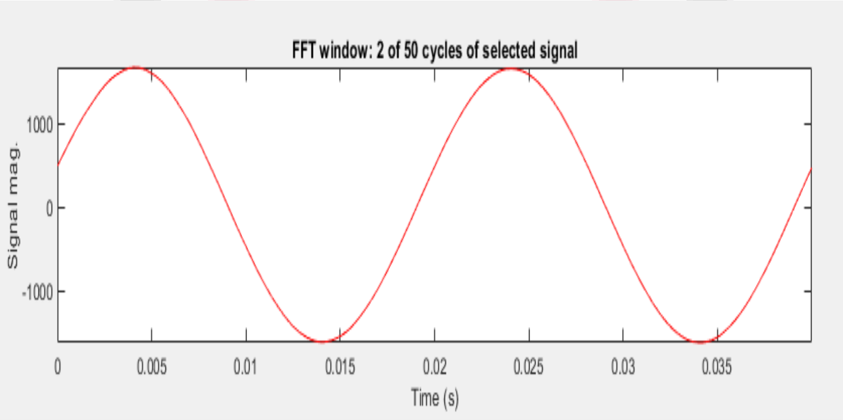

Figure 32: FFT Analysis of current at the grid

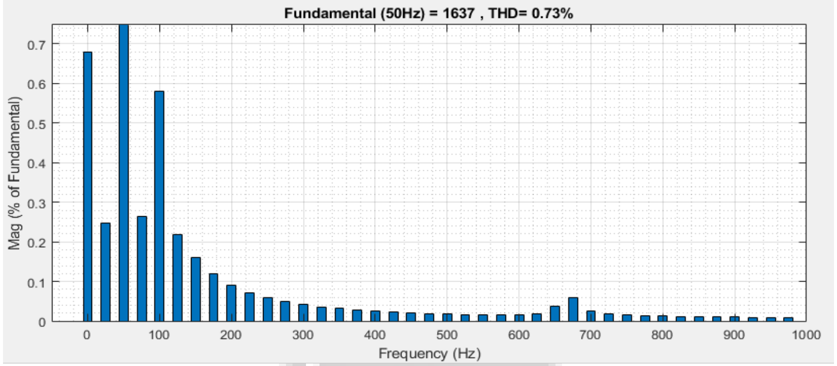

Figure 33: THD% in current at the grid

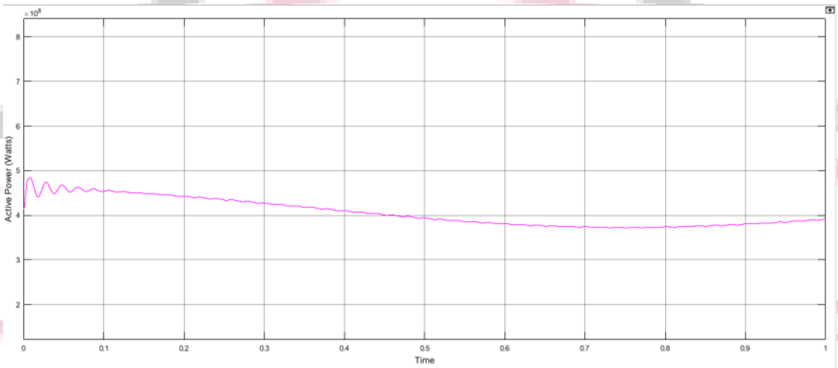

Figure 34: Active power at the grid in two area wind-PV-FC integrated system with Dynamic system optimization control

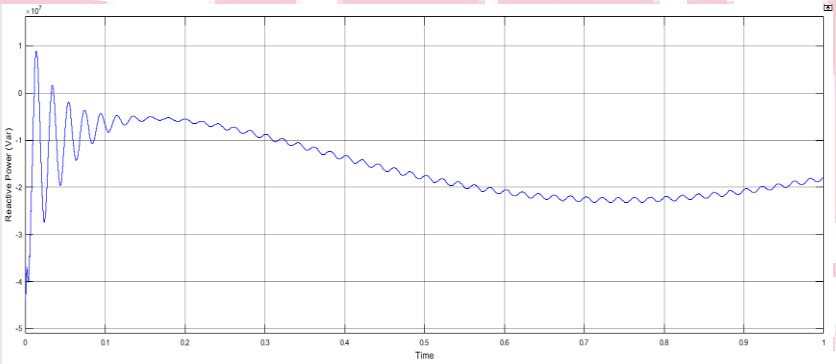

Figure 35: Reactive Power at the grid in two area wind-PV-FC integrated system with Dynamic system optimization control

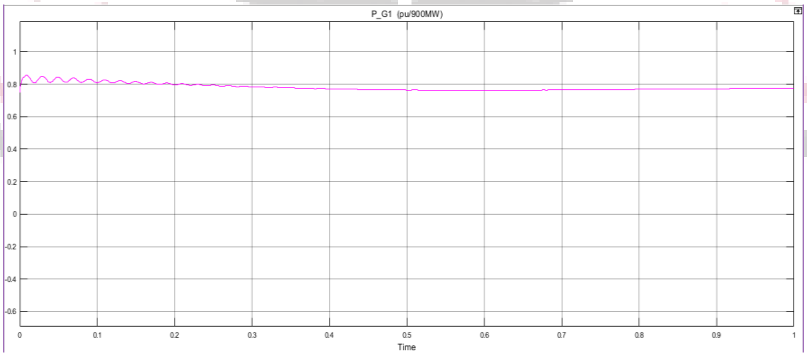

Figure 36: Power stability in p.u at the generating terminal of machines with Dynamic system optimization control

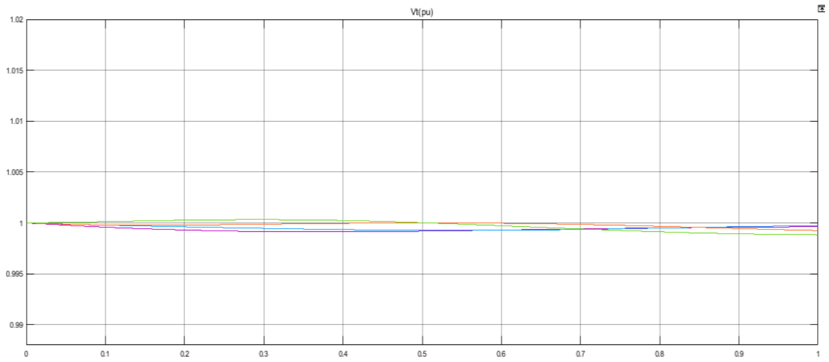

Figure 37: Rotor Speed variations on wind/Solar/FC integration with Dynamic system optimization control

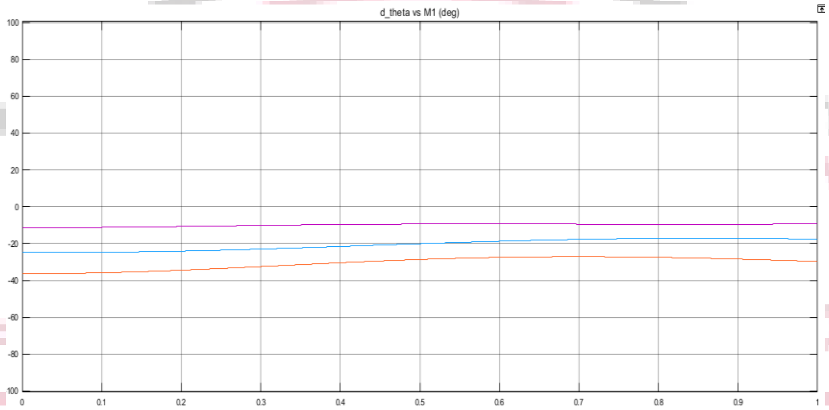

Figure 38: Rotor angle deviation in machines with wind/solar/FC integration and controller

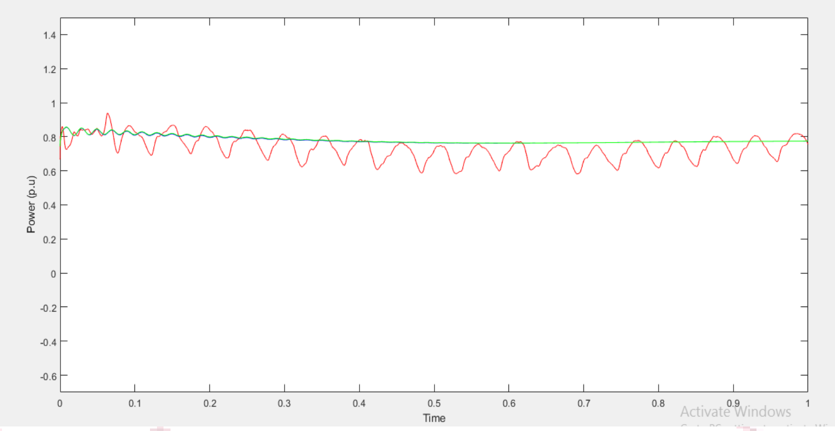

Figure 39: Comparative graphs of power stability in p.u at the generation terminal

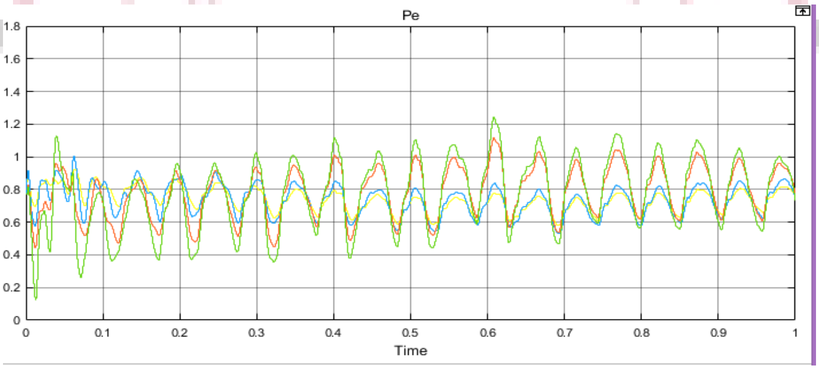

Figure 40: Electrical power Pe (p.u) in machines in case 1

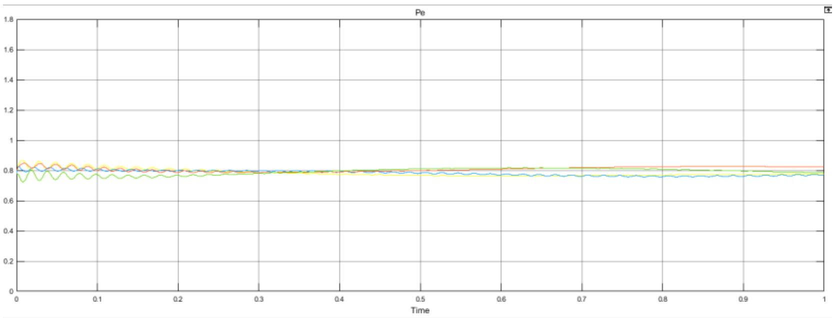

Figure 41: Electrical power stability [Pe (p.u)] in machines in case 2

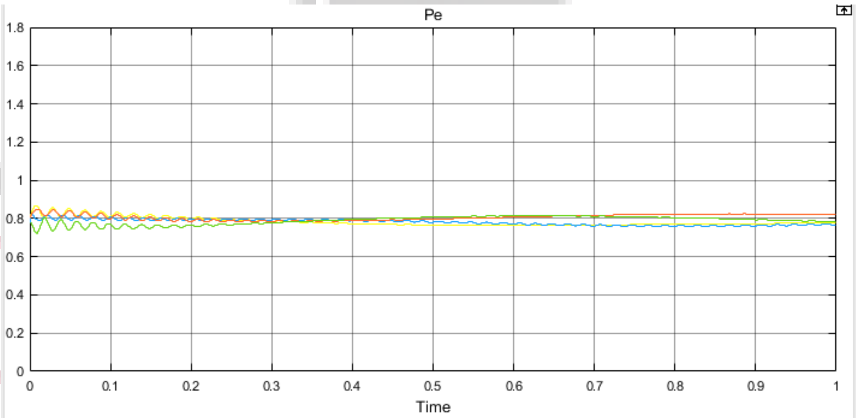

Figure 42: Electrical power stability [Pe (p.u)] in machines in case 3

The graphs depict the electrical power Pe of the machines in the two area system on integration with wind energy resources and further with solar and Fuel cell as well. The graph in case 2 and three shows more stable power of the machines in which the proposed Dynamic System Optimization control has been incorporated.

Table 3: Comparison of using Dynamic System Optimization control while integrating renewable resources in two area system

Systems	THD% in voltage	THD% in current
Case 1:	9.71 %	11.38%
Case 2:	1.34%	0.70%
Case 3:	1.36%	0.73%

VI. Conclusion

Grid-connected systems have a number of technical difficulties, including Power Quality Problems, Power and Voltage Deviation, Stockpiling, Security Requirements, and Islanding. Harmonics, voltage, as well as frequency fluctuations are all problems with power quality. The kundur two-area system was chosen as a test system to investigate system performance in the presence of renewable energy-based generating capacity. The straightforward incorporation of these resources was investigated for rotor angle stability, power stability at machine producing points, and the tier of deformations in the voltage and current waveforms of the grid system. The work proposes a universal dynamic system optimising control for overall system stability improvement. The MATLAB/SIMULINK environment serves as the design and implementation platform for the system. By incorporating a wind energy system excluding a stochastic optimization controller in area 1 and then developing systems with both solar and wind with a dynamic optimization control system in area 2, the impacts on the two area four machine system were researched. The research will also include the incorporation of a fuel cell system in Area 1.

The system calculations are done using a neural network-based forward learning algorithm to perform accurate from the dynamics controller. The system produced the following key conclusions:

- The THD percent in voltage was 1.36 percent, and the THD percent in current was 0.76 percent in the final system with wind/solar/FC with suggested dynamic system optimising control for dynamic stability improvement, which is significantly lower than in the system without controller, which had THD percent in voltage of 9.71 percent and THD percent in current of 11.38 percent at the time of incorporation.
- The control scheme in the power system also stabilised the rotor angle stability as well as power consistency at the juncture of generation bus.

As a result, the suggested NN learning-based dynamic system optimising control for dynamic stability improvement may be a better alternative for trying to integrate any type of renewable power resource-based generating system with the grid, as it can alleviate almost all of the quality problems that arise as a result of it.

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