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Optimum Controller Design Go Overall Quality Enhancement of System with Hybrid Renewable Energy Sources

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Abstract: **Grid-tied photovoltaic systems are power-generating systems that are connected with grids. Designing of a grid integrated solar wind hybrid energy system for driving loads for improving its reliability and efficiency. This study of designing an inverter control that attains lower distortion level in the voltage as well as current waveforms. The controller should reduce the spikes at the transient loading point when the system is subjected to sudden load changes. The system is to be integrated with the fuel system also to obtain the energy efficiency. The fuel system would be connected in parallel to the DC voltage output of the solar/wind hybrid system. And Improvement in the reactive power output from the system by the inverter control by designed hybrid system that can compensate the reactive power requirement when required. This project should attain the hybrid solar/wind/fuel system with proposed controller to improve the output parameters. The final hybrid system with fuel cell integration was studied for the total harmonic distortion in the voltage and current waveform. The distortion level in the voltage waveform was found to be 0.39% and that in the current waveform was 1.95%. It is under the IEEE acceptable limits.**

Keywords: **hybrid system, solar, DC, grid system.**

I. INTRODUCTION

Grid-connected photovoltaic systems are electricity generation systems connected to grids. The photovoltaic solar energy generated must be processed using an inverter connected to the grid before it can be commissioned. This inverter is located between the photovoltaic solar generator and the power grid. It can be a single unit or a collection of small inverters connected to individual photovoltaic units. Due to the lower costs of power electronic devices and advances in renewable energy technology, the energy industry is strongly encouraged to use photovoltaic solar energy and connect it to a medium or low voltage distribution network. The renewable electricity market has grown enormously in recent years. Due to lower costs, solar and wind energy are playing an increasingly important role and are competitive with fossil fuels in many countries.

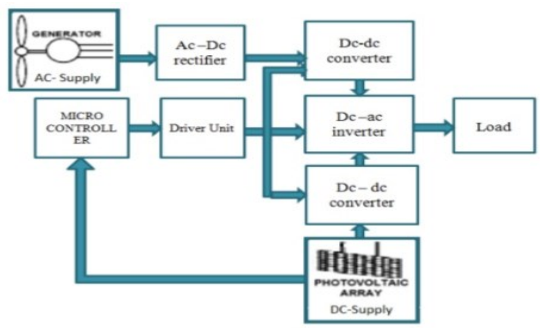

Fig. 1. Block diagram of hybrid wind solar energy system

II. LITERATURE REVIEW

Majid Tahmasbi Fard et al. [1] this article presents a hybrid power generation system based on energy inverter (CSI) that uses wind turbines and photovoltaic cells (PV). A synchronous permanent magnet generator (PMSG) is connected to the CSI via a diode rectifier and a step-down converter, with which the rotor speed is controlled. Another step-down converter is used to control the monitoring of the PV's maximum power point. The operation of the proposed system is examined under normal conditions and mains voltage drop. According to the new grid codes, most electricity generating units must remain connected to the grid during voltage drop conditions and supply reactive current to the grid as defined by the grid codes. The CSI has a residual current limitation function which makes it suitable for use in grid-connected applications and in particular in conditions of voltage drop.

B.Venkatasamy et al. [2] In this paper are the power is being generated in the wind generating stations even after the average life span. But, when the wind turbine is used after this average life span the maximum power that can be generated will be reduced due to aging of mechanical parts and maintenance factors. Also, the other equipment's like transformer and switchgear can be operated with reasonable efficiency even after the maximum working life span of the wind turbine. Hence utilization of a wind generating station can be improved by connecting a solar power system with the existing transformer and switch gear setup which forms hybrid wind-solar energy system. The various possible features that can be added in the hybrid system are discussed and analyzed in this paper.

J. Hossain et al. [3] this article limits attention to solar energy resources, solar panels and the storage system to provide the necessary electrical support. This letter is particularly related to the mathematical modeling of solar systems and the simulation of the different aspects and cases of the system. In addition, the zinc bromide battery and the lithium ion battery are described with explanations on their performance and associated simulations. The performance of the microarray systems with the memory unit are then analyzed for various parameters in the case of island mode operation and network mode operation. All the results are meticulously verified by Matlab simulations.

Aida Baghbany Oskouei et al. [4] in this article, an asymmetric quinary inverter with inductors and transformers coupled in hybrid systems including photovoltaic (PV) and wind energy is proposed and used. In addition to the advantages of a multi-stage inverter, this inverter generates a voltage of twenty-five levels and has only one direct current source. So it is sufficient for hybrid systems, which prevents an increase in the DC link and facilitates system control. The proposed structure also provides isolation in the system and the number of switches is reduced in this topology compared to other multilevel structures. In this system, the battery is used as a backup battery, photovoltaic and wind are complementary.

III. Objective

The work proposes to attain following key objectives from the research:

- Designing of a grid integrated solar wind hybrid energy system for driving loads for improving its reliability and efficiency.
- Designing an inverter control that attains lower distortion level in the voltage as well as current waveforms. The controller should reduce the spikes at the transient loading point when the system is subjected to sudden load changes.
- The system is to be integrated with the fuel system also to obtain the energy efficiency. The fuel system would be connected in parallel to the DC voltage output of the solar/wind hybrid system.
- Improvement in the reactive power output from the system by the inverter control by designed hybrid system that can compensate the reactive power requirement when required.
- This project should attain the hybrid solar/wind/fuel system with proposed controller to improve the output parameters.

IV. Methodology

A. Modeling of hybrid system

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 paper discusses the basic modeling structures of solar energy system, and Wind energy system along with modeling of PSS controls.

B. PV Module modeling

Photovoltaic energy is abundant in the environment and free of pollution. The type of output power of the photovoltaic system depends on the geographical position. The photovoltaic system is a possible source of energy with which it is possible to overcome dependence on fossil fuels [4]. The representation of the hybrid photovoltaic generation unit consisting of a photovoltaic generator, a DG, an inverter and a battery system. The different combinations of hybrid PV / diesel battery storage systems and DG auxiliary units are examined in order to examine the potential and efficient use of diesel PV systems to meet consumer load requirements [5].

Classification of autonomous and grid-connected photovoltaic systems Photovoltaic systems are divided into two categories: autonomous and interactive systems on the network or connected to the network. This classification of photovoltaic systems depends on their operational and functional requirements, on their component configurations and on their connection to other electrical loads and energy sources. Furthermore, photovoltaic systems can operate independently or connected to the electricity grid. They are designed to provide AC or DC power supplies and can be connected to energy storage systems and other alternative energy sources. As already mentioned, the photovoltaic systems connected to the network are designed to operate in parallel and be connected to the power supply network.

The energy conditioning unit or the inverter is the main component of the photovoltaic systems connected to the network that convert the direct current generated by the photovoltaic generator into alternating current that meets the voltage and quality requirements of the supply network current for direct purposes on the devices or send them to the supply network to obtain the feed in compensation for the price. If the network is not powered, the PCU automatically cuts off the power to the network.

A bidirectional interface, located on an on-site distribution field or at the entrance of a service, allows alternating current generated by the PV system to supply electrical loads on site or to re-inject the grid if the power of the PV system is greater. For such local performance is a top-up requirement. If the electrical loads are greater than the power of the photovoltaic system, especially at night and in cloudy weather, the power balance required by the loads is received by the electricity company. This is a safety function if the network has failed for maintenance or repair to ensure that the PV system is no longer used and returned to the power supply [9].

A photovoltaic system connected to the grid without accumulating backup energy (ES) is environmentally friendly and is often used by people because of the reduction in maintenance and costs. However, in the event of a power outage during the night or in cloudy weather, the system should stop operations until AC power is available. Photovoltaic systems connected to the grid with a backup ES are normally connected to the power grid. This configuration offers numerous advantages, for example the excess sale of photovoltaic electricity production to the grid, the recharging of the battery system during off-peak hours and the purchase of grid electricity to supply the loads when the photovoltaic energy and the battery is insufficient. Photovoltaic cells have a single operating point where the cell's current (I) and voltage (V) values provide maximum output power. These values correspond to a certain resistance, which is equal to V / I. Figure 2 shows a simple equivalent circuit diagram of a photovoltaic cell.

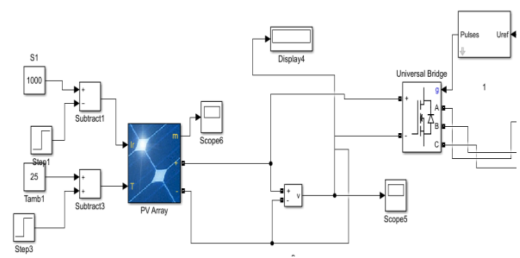

Fig. 2. Modeled solar system

A cell series resistance (Rs) is connected in series with parallel combination of cellphotocurrent (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

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

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

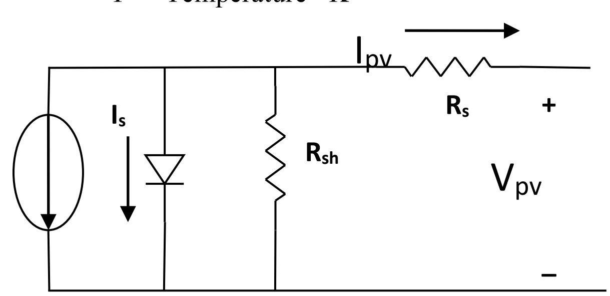

Fig. 3. Equivalent circuit of solar PV cell

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

$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000}$ Eq (2)

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.

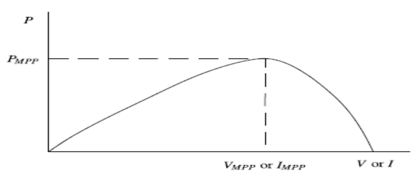

Fig. 4. Characteristic PV array power curve

Table 1 PV module Parameters

Model	1Soltech 1STH
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	1000 wb/m^2
Temperature	30^{0}C

C. wind energy system modeling

Wind energy is also available free of charge in the environment, an environmentally friendly source of energy. The output power of the wind turbine varies according to the wind potential of the design site. The prerequisite for a viable solution and a techno-economic wind system is the selection of a geographical position higher than the wind potential [6]. The feasible and economic model of the wind system to compare the performance of different wind turbines in different places is examined with regard to the average speed and properties of the turbine [6].

D. Generator

The energy in the wind turns two or three Propeller like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. Thus generator converts mechanical energy of wind turbine rotor into electrical energy

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 [3][7].

2

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

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

$\lambda = \frac{\omega_m R}{v}$ Eq (4)

where$\omega_m$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:

$T_m = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3 \frac{1}{\omega_m}$ Eq (5)

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

Then Power output is given by

$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}} v^3$ Eq (6)

A generic equation is used to model the power coefficient *Cp*based on the modeling turbine characteristics described in [2], [7-9] and [10] as:

$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)}$ Eq (7)

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.

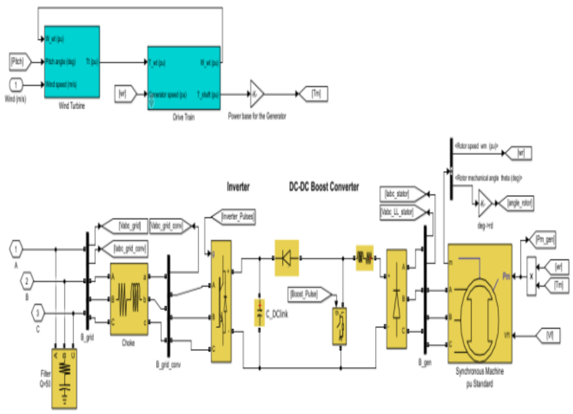

Fig. 5. Modeled Wind system

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 :Wind energy system parameters

Wind speed	11 m/sec
Number of wind turbines	80
Nominal power	2 MW
Frequency	50 hertz
Line to line voltage	410 V
Friction factor	0.01
Number of poles	1
Inertia constant	0.62

E. Proposed Work

The work first was focuss3ed on making a hybrid solar wind energy system connected to the grid. The solar system specifications as mentioned in the previous chapter were taken for analysis. The system is made to drive different. The voltage and current output in the 30Kwatt load line has been shown below.

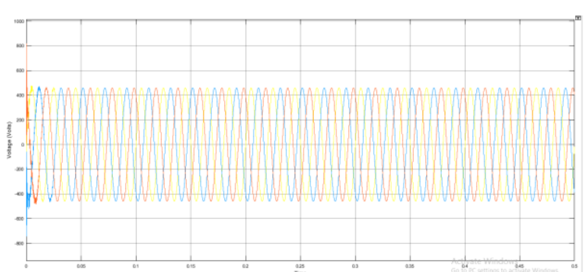

Fig. 6. Voltage at the load line

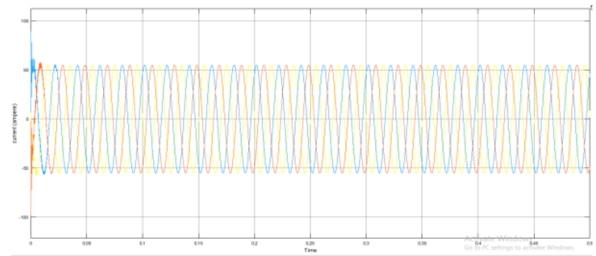

Fig. 7. Current at the load line

The operating line voltage for the load interconnection is maintained to be 500 volts. The system is made to drive another 30 KW load from the system connected in parallel. The above analysis was carried out with the basic voltage regulatory control for the inverter. In order to study the effect of our proposed controller, the same system was subjected to the proposed current regulatory hysteresis band integrated PI controller for inverter an its effect on the current and voltage waveforms at the load terminal was analyzed. The distortion level in the current and voltage waveforms were studied and were found to be as follows.

Table 3: Comparative values of distortions using self designed control

Parameters	System with basic voltage regulation control	System with proposed controller
THD% in voltage	1.47%	0.29 %
THD% in current	7.5 %	1.71

It was concluded that by using the designed controller in the hybrid solar wind energy system the distortion level in the voltage and current waveforms was significantly reduced. This proves the efficiency of the designed controller as a total harmonic level reducer in the circuit and thereby making it a better choice. Further the analysis was carried forward to transient loading conditions when a load was suddenly switched on into the line at 0.2 seconds of simulation time

F. Load analysis

For this analysis the changes in the current waveform was analyzed at the interval when the load was switched into the lined suddenly. For this purpose three phase line breaker was used along with the 30KW load whose initial state remains at off condition. At 0.2 seconds the breaker switches its state to on and the load gets connected to the line. The line voltage remains the same tat is 500 volts. The changes in the current waveform were studied by analyzing the THD level in current waveform due to sudden loading of line.

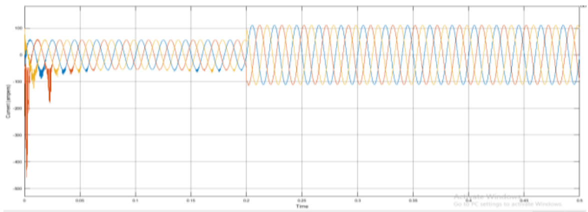

Fig. 8. Current drawn from the load terminal with basic voltage regulation control

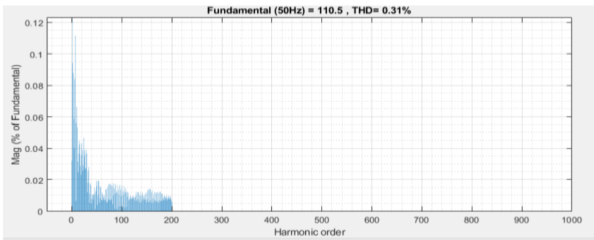

Fig. 9. THD% in Current drawn from the load terminal with basic voltage regulation control at transient loading at 0.2 seconds

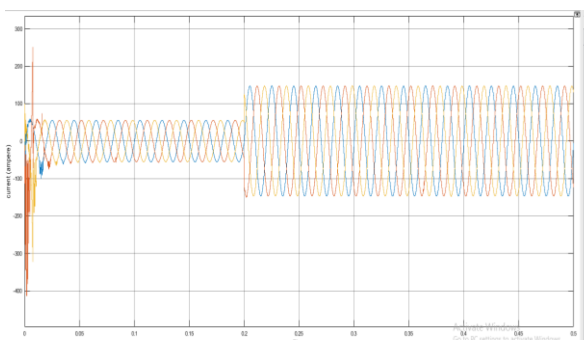

Fig. 10. Current at the load terminal with proposed controller

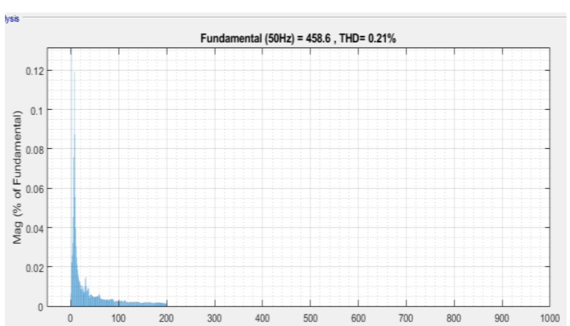

Fig. 11. THD% in Current at the load terminal with proposed controller

Form the above figures it can be concluded that the distortion level in the current drawn at the load terminal at the transient loading at 0.2 seconds has reduced. The changes in the THD level is from 0.31% in the current waveform with voltage regulation control to 0.21% with the proposed multi objective adaptive constraints approach for hybrid quality enhancement in system. Though the changes in both the system is small the designed controller has proven to be still an effective choice for driving the inverter in the system.

G. *Fuel system integration*

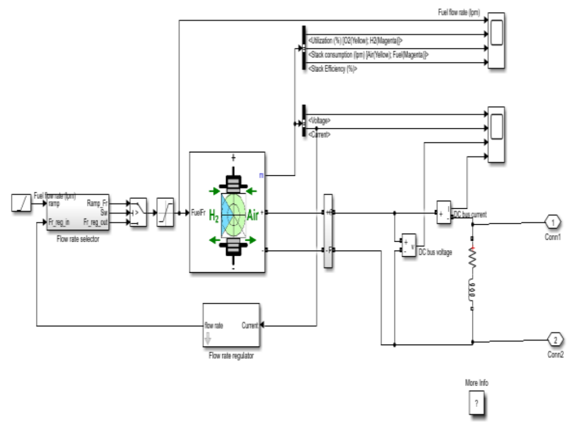

Fig. 12. MATLAB/SIMULINK model of fuel system

PEMFC is an electrochemical device that converts the chemical energy contained in a reaction between a fuel, hydrogen and an oxidant, oxygen, into electrical energy. A polarization voltage is applied to the electrochemical cell to induce electrochemical reactions on the two electrodes. Water is introduced into the anode and dissociated into oxygen, protons and electrons. Protons are driven by an electric field through the PEM to the cathode, where they combine with electrons that come from the external circuit to form hydrogen gas.

Fuel cells are compact and silent energy generators that use hydrogen and oxygen to generate electricity. The transport sector is the main potential market for fuel cells and car manufacturers invest heavily in research and development. However, power generation is seen as a market where fuel cells can be placed on the market much faster. Fuel cells can achieve a high level of efficiency (35% -60%) compared to conventional technologies. The figure shows the approach with which the system was integrated into the solar / wind system.

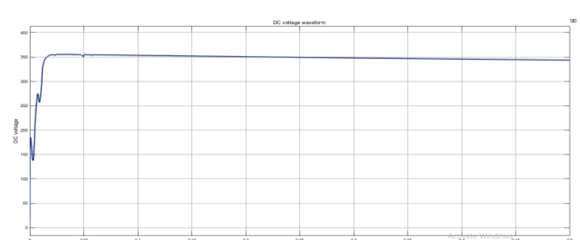

Fig. 13. Common DC link voltage for all the energy resources

The solar/wind/fuel energy system was configured were configured to be connected in parallel having common voltage the figure depicts the Common DC voltage line through which the three renewable energy resources are being connected it is maintained approximately to be 350 volts.

H. Boost converter Designing

The Boost Converter block represents a converter that steps up DC voltage as driven by an attached controller and gate-signal generator. Boost converters are also known as step-up voltage regulators because they increase voltage magnitude.
The Boost Converter block allows you to model an asynchronous converter with one switching device or a synchronous converter with two switching devices like GTO — Gate turn-off Thyristor, IGBT, MOSFET and Thyristors.

The Boost Converter block allows you to model an asynchronous converter with one switching device or a synchronous converter with two switching devices like GTO — Gate turn-off Thyristor, IGBT, MOSFET and Thyristors. In our work we have used a boost converter that is regulating the DC link voltage and stabilizing it for long run. The figure shows the DC voltage output from the system after using the DC-DC boost converter. IT was found to be improved to approximately 390 volts after boost conversion. This improves the voltage input to the inverter for DC/AC conversion utilizing metaheuristic approach for quality enhancement controller

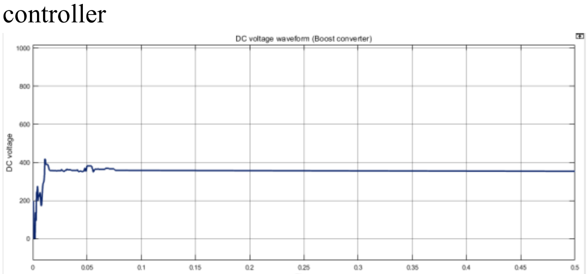

Fig. 14. DC voltage waveform after the boost converter

V. RESULTS

A Hybrid Power System (HPS) utilizes two or more energy sources, power converters and/or storage devices. The main purpose of HPS is to combine multiple energy sources and/or storage devices which are complement of each other. Thus, higher efficiency can be achieved by taking the advantage of each individual energy source and/or device while overcoming their limitations. In this chapter the analysis of the system having hybrid solar/wind energy system with basic voltage source control for the inverter is done. The output from the system is then compared with another system having solar/wind/ fuel cell energy resources in a hybrid form and the inverter is controlled by self-designed multi objective adaptive constraints approachfor the inverter control for enhancing all the output parameters as compared to the previous system

The result has discussed output from the hybrid system using stabilizer in the following mentioned cases:

CASE 1: Hybrid PV/wind system integrated with the grid with basic voltage source controller
CASE 2: Hybrid PV/wind/fuel system integrated with the grid with proposed metaheuristic approach for quality enhancement for inverter
CASE 1: Hybrid PV/wind system integrated with the grid with basic voltage source controller

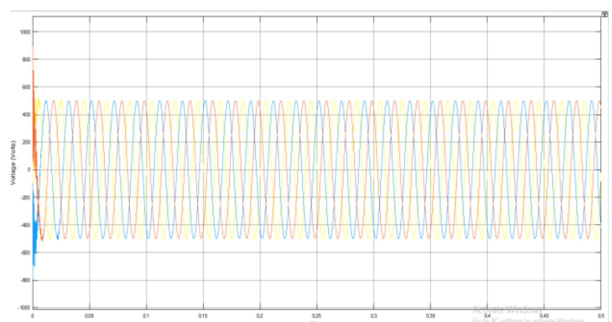

Fig. 15. Voltage output from the solar/wind hybrid system with voltage source controller

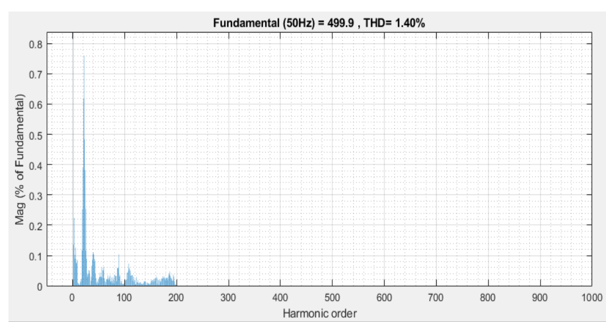

Fig. 16. THD% in voltage output from the solar/wind hybrid system

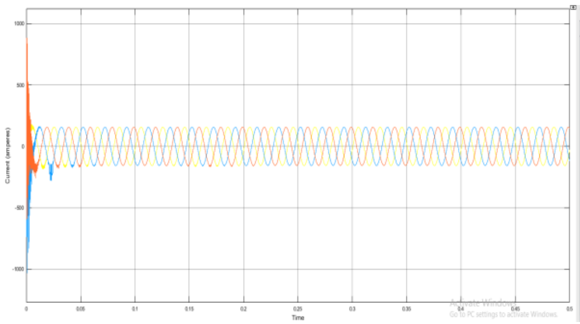

Fig. 17. Current output from the solar/wind hybrid system with voltage source controller

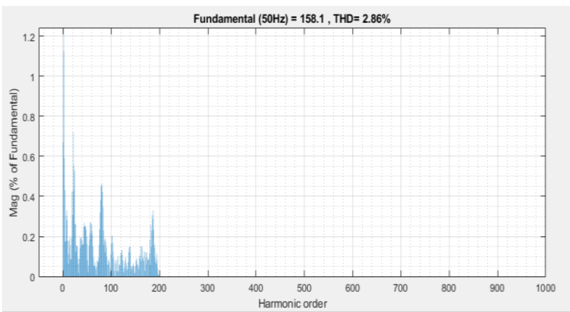

Fig. 18. THD% in Current output from the solar/wind hybrid system

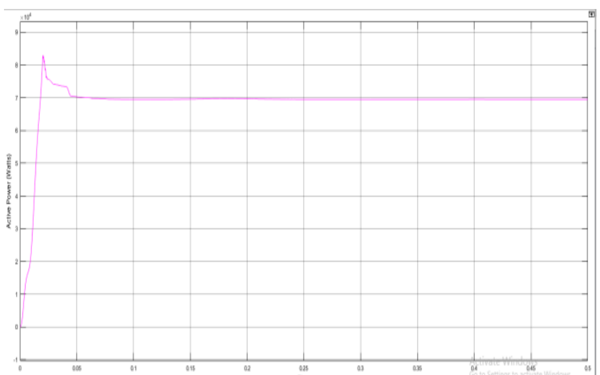

Fig. 19. Active power output from the solar/wind hybrid system with voltage source controller

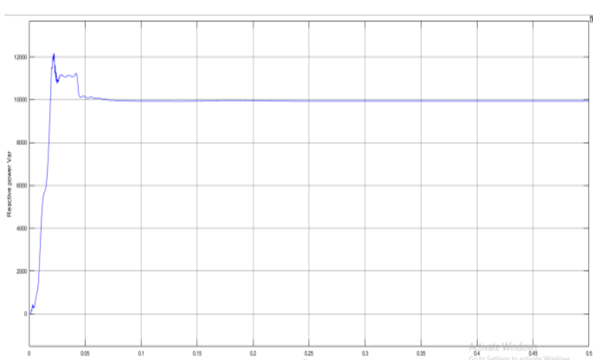

Fig. 20. Reactive power output from the solar/wind hybrid system with voltage source controller

The system voltage has been found to be 500 volts. The current output available at the load terminal after basic voltage regulation based control was found to 155 amperes. On finding the active and reactive power outputs available at the load terminal in this case the results had shown approximately 70000 Watts output and approximately 9936 var output.

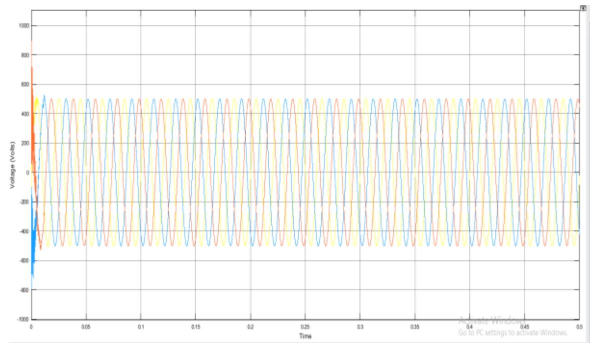

Fig. 21. Voltage output from the hybrid solar/wind/fuel cell system having multi objective adaptive constraints approach for quality enhancement controller

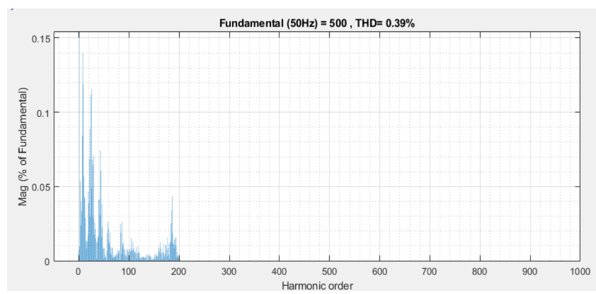

Fig. 22. THD% in Voltage output from the proposed hybrid solar/wind/fuel cell system

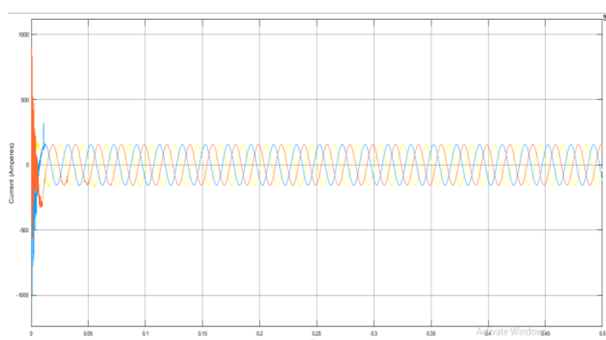

Fig. 23. Current output from the hybrid solar/wind/fuel cell system having multi objective adaptive constraints approach for quality enhancement controller

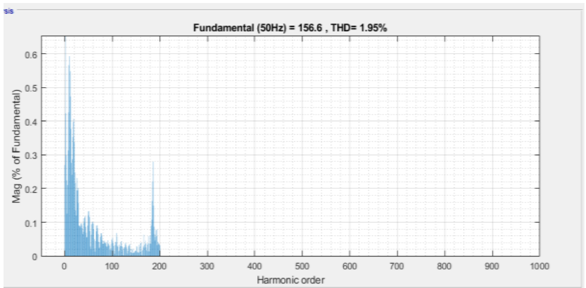

Fig. 24. THD% in current output from the proposed hybrid solar/wind/fuel cell system

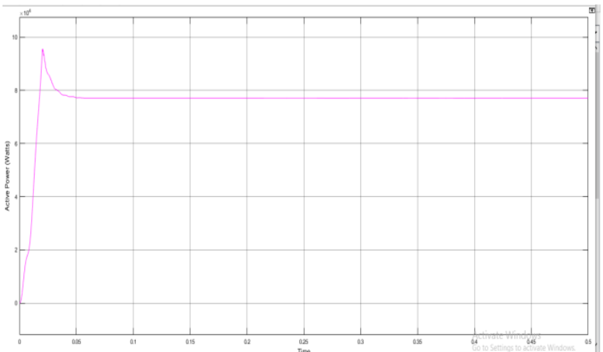

Fig. 25. Active Power output from the hybrid solar/wind/fuel cell system having multi objective adaptive constraints approach for quality enhancement

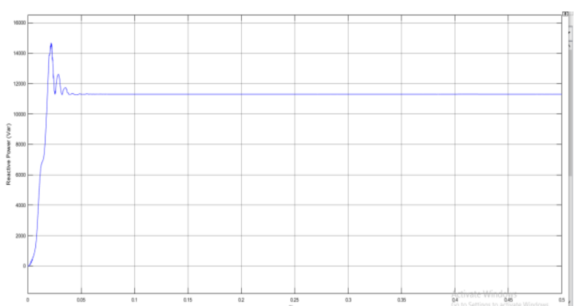

Fig. 26. Reactive power output from the hybrid solar/wind/fuel cell system having multi objective adaptive constraints approach for quality enhancement controller

The system voltage has been found to be 500 volts. The current output available at the load terminal after basic voltage regulation based control was found to 157 amperes. On finding the active and reactive power outputs available at the load terminal in this case the results had shown approximately 77090 Watts output and approximately 11300 var output.

VI. Conclusion And Future Scope

Renewable energy sources also called non-conventional type of energy are continuously replenished by natural processes. Hybrid systems are the right solution for a clean energy production. Hybridizing solar and wind power sources provide a realistic form of power generation. Here, a hybrid wind solar energy and fuel cell system with a converter topology is proposed which makes use of Boost Converter and proposed metaheuristic approach for attaining quality control through inverter. The metaheuristic approach is a multi objective adaptive constraints approach for dealing with the system constrains. The operational optimization and power-electronics based voltage–power control was developed, and the functioning was demonstrated through simulation.

Power electronics is a key enabling technology in connecting all energy resources to the dc bus. Their control can functionally enhance the output parameters of the hybrid system. The inverter controller was designed keeping in mind the various parameters of the power system on their respective improvement. The following main conclusions were drawn from the work.

- The designed control was first analyzed for harmonic level distortion in the voltage and current output waveforms at the starting. It was found that the proposed approach has reduced the distortion in voltage as well as current waveform.
- Further the control was analyzed for sudden loading conditions. The distortion in current waveform was studied and it was found to be less in the proposed controller as compared to the voltage source control.
- The system reactive power has enhanced from the 9936Var to 11300Var
- The active power has also rises in accordance with the increase in input to the inverter to approximately 77090 Watts which is very stable.
- The final hybrid system with fuel cell integration was studied for the total harmonic distortion in the voltage and current waveform. The distortion level in the voltage waveform was found to be 0.39% and that in the current waveform was 1.95%. It is under the IEEE acceptable limits.

A. *Future Scope*

Installing this solar-grid hybrid system will be actually very fruitful because it will reduce the grid dependency. On the other hand, this system promotes green energy which is very important because all the energy sources are depleting day by day. So, people must look for new renewable sources and solar power is definitely one of the best choices in this purpose. In future work an adaptive neural network based control for improved power quality 3 phase grid integrated with nonlinear and linear loads will be designed for this system having three sources in the form of solar/wind/fuel cell based hybrid system. The expected control scheme regulates the system voltage and improves the power quality in a very effective manner.

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