Power Enhancement by PSO Regulatory Fuzzy Control of Inverter in Grid Tied Solar PV system

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Abstract : Solar energy available in large magnitude makes it a highly appealing source of electricity. Solar energy development is affordable and clean will have longer-term benefits. In this work we have first designed solar PV system in MATLAB/SIMULINK environment. The output DC is passed through DC/DC converter before its conversion to AC via a inverter. The inverter control is intended to be enhanced via AI techniques such that the power output is enhanced and improved so that this power can be further sent to the grid. The AI techniques chosen is PSO and fuzzy specifically designed for photovoltaic systems. The proposed system is also integrated with the wind energy system before its integration with grid to make the system more reliable. The system voltage is maintained constant to be 400 Volts. It was found that system designed with PSO regulatory FUZZY controller as seen considerable improvement in active power output from the system from approximately 3KW in conventional inverter to 8KW in the proposed scheme.

***IndexTerms* - Artificial Intelligence, Hysteresis, PSO, Fuzzy, HERS.**

I. Introduction

Electricity is the important factor for industrialization, urbanization, financial growth of any country [1]. There are different types of conventional and non-conventional energy sources used to generate electricity. Solar and wind energy system is one of the most prominent sources of energy. The utilization of solar and wind energy system has become increasingly popular due to modular and environment friendly nature [2].

The field of solar–wind has experienced a remarkable growth for past two decades in its widespread use of standalone to utility interactive solar–wind systems [3]. Solar and wind energy system works normally in standalone or grid connected mode, but the efficiency of these sources is less due to the stochastic nature of solar and wind resources. The hybrid renewable energy sources with grid integration overcome this drawback of being unpredictable in nature.

Hybrid renewable energy system (HRES) is a combination of renewable and conventional energy source, it may also combine two or more renewable energy sources that work in standalone or grid connected mode. The HRES that combines solar and wind energy key resources, operates in two modes: simultaneous and sequential. In simultaneous mode, the solar and wind energy system produces energy concurrently while in sequential mode they produce electricity alternatively [4,5].

The significant characteristics of HRES are to combine two or more renewable power generation technologies to make proper use of their operating characteristics and to obtain efficiencies higher than that could be obtained from a single power source. This paper presents a review of solar–wind hybrid renewable energy system covering issue such as pre-feasibility study, modeling, controlling, optimization technique, reliability and power quality of the system [6-7].

II. LITERATURE REVIEW

T. H. Rini and M. A. Razzak [1] This paper presents the analysis of power to observe the reliability of a solar-wind hybrid energy system which consist of a Photovoltaic (PV) array, a wind turbine, a Permanent Magnet Synchronous Machine (PMSM), a three phase diode bridge rectifier, a LTC3784 controller, a grid interface inverter, a step-up transformer and a low-pass LC filter. The power from solar-wind hybrid system is combined and then the output from here is transferred to the controller LTC3784 for a fixed output voltage which is then inverted using an SPWM-based full-bridge inverter, and stepped up using step-up transformer to feed into the utility grid. Both input and output power has been verified to check the reliability of the system. The proposed model is mathematically designed and simulated by PSIM and LT spice software.

A. V. Pavan Kumar et al.[2] In this paper a two-diode model of PV cell is implemented in Matlab Simulink with reduced four required parameters along with similar configuration of the built-in model. This model allows incorporation of MPPT controller. It is done As the Solar power conversion is a low efficient conversion process, accurate and reliable, modeling of solar cell is important. Due to the non-linear nature of diode based PV model, the accurate design of PV cell is a difficult task. A built-in model of PV cell is available in Simscape, Simelectronics library, Matlab. The equivalent circuit parameters have to be computed from data sheet and incorporated into the model.

M. Y. Zargar et al.[3] This paper focuses on the development of Stand Alone hybrid Wind-Solar Photovoltaic system where energy storage device is used for voltage control. The system is modelled considering dynamic wind speed and solar irradiance level. Both wind and solar grids are connected at dc link where energy storage system is installed for voltage control. Maximum power point tracking (MPPT) used increases the efficiency of solar photovoltaic (SPV) system. The simulation of MPPT algorithm to track maximum power is also presented where pulses are supplied to boost converter using perturb and observe methodology. LC filter is used to filter ripples. Simulation experiments are carried out to demonstrate the effectiveness of the overall system.

H. Patsamatla et al.[4] This paper proposes a universal control algorithm to harvest maximum possible power from wind-solar hybrid energy system for battery storage application. The universal control strategy improves the performance of the hybrid system for large variations in wind velocity and solar radiation conditions with reduced complexity of the controller. Thus the system achieves higher reliability and better energy yield, especially in poor environmental conditions. The algorithm also maintains constant voltage at the DC bus.

III. OBJECTIVE

The work is designed in order to obtain the following key objectives:

- Designing of solar PV system in MATLAB/SIMULINK environment. The output DC is passed through DC/DC converter before its conversion to AC via a inverter.
- The inverter control is intended to be enhanced via AI techniques such that the power output is enhanced and improved so that this power can be further sent to the grid. The AI techniques chosen is PSO and fuzzy specifically designed for photovoltaic systems
- The comparative analysis of output waveforms is to be done to analyses the efficiency of the proposed controller.
- The system is also integrated with h]the wind energy system such that a hybrid system is obtained and it is more reliable in terms of power injection to the grid

IV. METHODOLOGY

The modeling of Dual Voltage Source Inverter system is done which is capable of feeding the load with either solar or wind resources depending on the availability thus making the system more reliable.

Modeling of various parts of the system has been discussed further. The modeled PV system with MPPT technique for its optimum operation, PMSG (permanent magnet synchronous generator) connected with the wind turbine has been discussed.

4.1 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. 1.

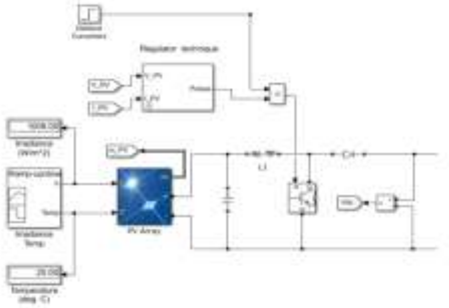

Figure 1 Modeled solar system

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 (l.6e^{-l9}C)

K - Boltzmann constant (l.38e^{-23}J/K)

n - Ideality factor (l~2)

T - Temperature ^{0}K

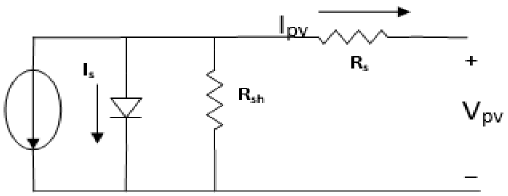

Figure 2 Equivalent circuit of solar pv cell

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

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000} \quad (4.1)$$

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

4.2 wind energy system modeling:

Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. The components of wind turbine have been modelled by the following equations.

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

$$P_{Turbine} = \frac{1}{2}\rho A C_p(\lambda,\beta)v^3 \qquad (4.2)$$

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:

$$\lambda = \frac{\omega_m R}{v} \qquad (4.3)$$

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:

$$T_m = \frac{1}{2}\rho A C_p(\lambda,\beta)v^3 \frac{1}{\omega_m} \qquad (4.4)$$

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

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.

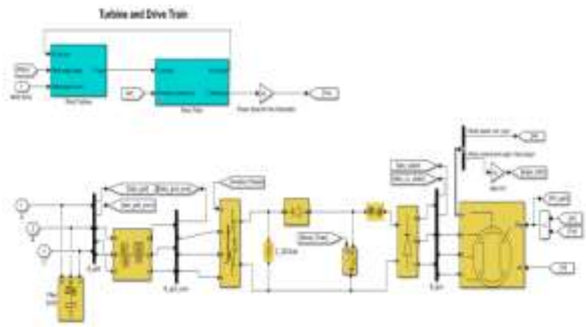

Figure 3 modelled Wind system

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

4.3 PSO algorithm regulatory fuzzy controller

Particle swarm optimization PSO is a novel swarm optimization algorithm that is firstly proposed by Kennedy as an evolutionary algorithm based on behavior of birds. PSO uses a set of particles that each one suggests a solution to the optimization problem. It is based on the success of all particles that emulates a population where the position of each particle depends to the agent position to detect the best solution P_{best} by using current particles in the population G. The position of any particle xi is adjusted by

$$x_i^{k=1} = x_i^k + v_i \qquad (4.7)$$

Where the velocity component vi represents the step size and is calculated by:

$$v_i^k = wv_i^k + c_1 r_1 (P_{best_i} - x_i^k) + c_2 r_2 (G - x_i^k) \qquad (4.8)$$

Where x is the inertial weight, c_1 and c_2 are the acceleration coefficients, r_1 and r_2 are random values that belong to the interval of [0, 1], $P_{best_i}$is the best position of particle i, and G is the best position in the entire population.

The operation given in flowchart can be analyzed in five steps that are initialization, fitness evaluation, updating the individual and global best value, updating the velocity and position of each particle, and convergence determination. In the first step, particles are randomly initialized in the distribution space, or are initialized on described grid nodes covering the search space.

Similarly, the initial velocity values are defined randomly. The fitness value of each particle is evaluated in the second step where the fitness evaluation is leaded to provide candidate solution to the objective function. The individual and global best fitness values are determined in the third step where $p_{best_i}$and g_{best} are respectively determined.

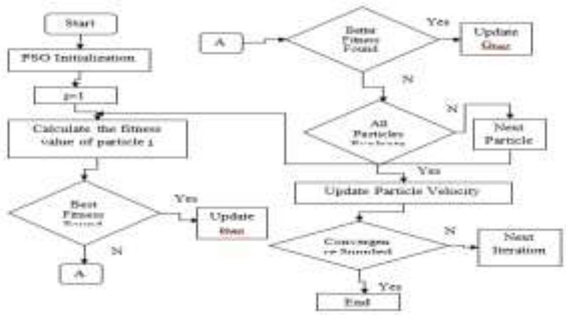

Figure 4 PSO- controller Technique implemented in MATLAB/SIMULINK

Then the positions are updated and replaced with better fitness values if they are found. The velocity and position of each particle are updated in the fourth step. The last step of the flowchart checks the convergence criterion. If the criterion is met, the process is finished. Otherwise, the iteration number is increased and procedure returns to step 2.

This algorithm is implemented in MATLAB taking DC voltage and current as input from the hybrid system. The optimised output is then taken forward to the fuzzy control for further optimisation. The fuzzy controller traces the AC output voltage from the system taking the DC input into account during calculation.

While designing of fuzzy based control following key algorithms is always taken into consideration.

Fuzzy logic works on the concept on deciding the output on the basis of assumptions. It works on the basis of sets. Each set represents some linguistic variable defining the possible state of the output. Each possible state of the input and the degrees of change of the state are a part of the set, depending upon which the output is predicted. It basically works on the principle of If-else-the, i.e. If A AND B Then Z.

Suppose we want to control a system where the output can be anywhere in the set X, with a generic value x, such that x belongs to X. Consider a particular set A which is a subset of X such that all members of A belong to the interval 0 and 1. The set A is known as fuzzy set and the value of $f_A(x)$ at x denotes the degree of membership of x in that set. The output is decided based on the degree of membership of x in the set. This assigning of membership depends on the assumption of the outputs depending on the inputs and the rate of change of the inputs.

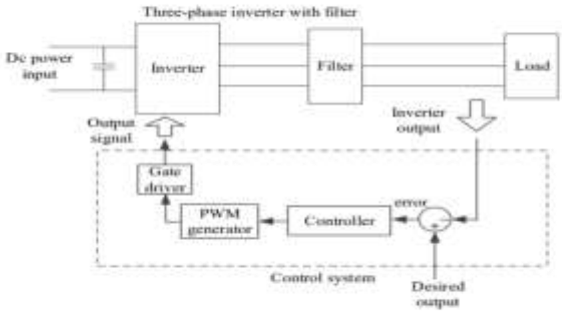

Figure 5 Block diagram of basic fuzzy based control

Every Fuzzy Logic block consists of two inputs and one output. The first input is the error and the other input is error-rate which is one-sampling before error values. For all the transmission line parameters the input and output membership functions are named similar. Traditional controller is replaced by a fuzzy controller. Input variables for the fuzzy controller are the error signal and the change of this error.

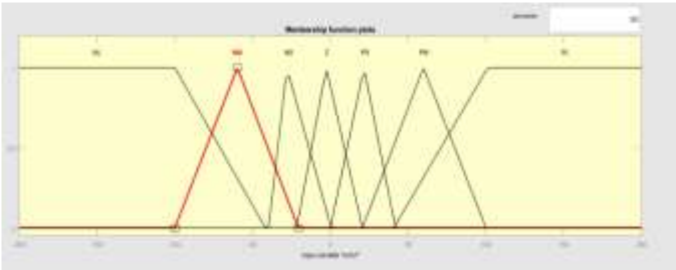

Figure 6 Input Variable (error) Normalized Membership Function

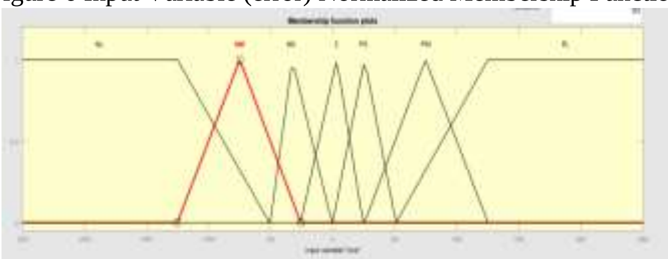

Figure 7 Input Variable (coe) Normalized Membership Function

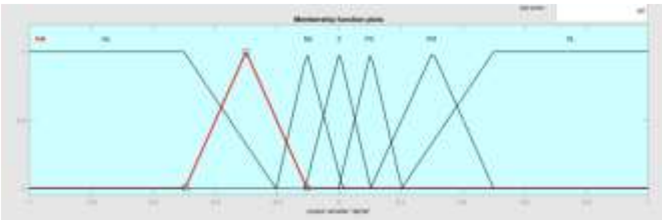

Figure 8 Output Variable Normalized Membership Functionijoi

Simulation is carried out for a fixed RES generation, which is greater than the load demand. The result of both scenarios are compared.

V. RESULTS

The first model was created using MATLAB/SIMULINK of solar energy system integrated with the grid and feeding a load. In the first model the inverter was modelled based on the hysteresis band controller and the voltage profile along with active power output was analyzed in MATLAB. Further in this work the active power output has been targeted to be improved by designing of AI based inverter control. Also the second model has been integrated with the wind energy system also in order to enhance the efficiency and reliability of the system. This will ensure continuity in case the solar system is not working properly or is under maintenance. The voltage profile and active power outputs from the system was again analyzed to observe the difference in the two models.

This chapter discusses the modelling of the systems in following two cases:

Case 1 : Solar PV Model with hysteresis band controller for inverter

Case 2: System with AI based PSO regulatory Fuzzy controller for inverter

Validation

Case 1 : Solar PV Model with hysteresis band controller for inverter

In this model solar photovoltaic system is being created in MATLAB/SIMULINK. The DC output from the solar system is converted into AC by utilisinga inverter. The inverter is provided with hysteresis band controller for generating pulses. Three arm IGBT based power converter required six pulses for its operation which is generated with the hysteresis band controller. After its conversion into AC the system is connected to a grid, also the load of 2 kilowatt is being driven.

The voltage, current, active power and reactive power waveform are being analysed after utilising the controller for the inverter

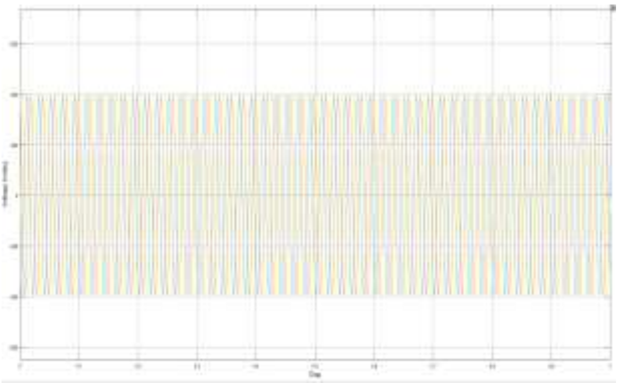

Figure 9 Voltage output from the solar system with hysteresis band controller for inverter

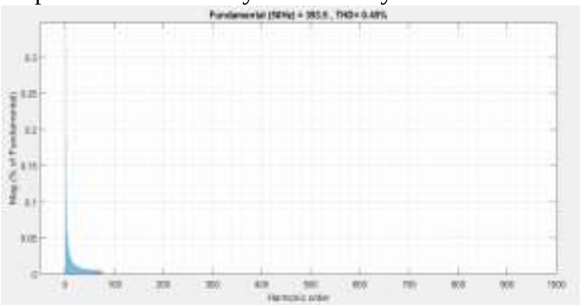

Figure 10 THD % in Voltage output from the solar system with hysteresis band controller for inverter

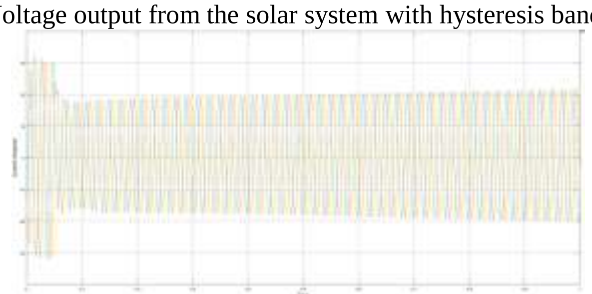

Figure 11 Current output from the solar system with hysteresis band controller for inverter

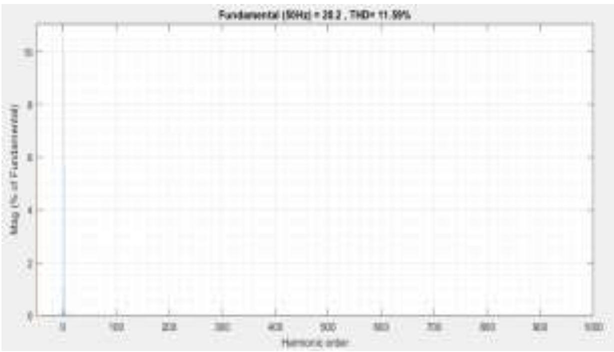

Figure 12 THD% in Current output from the solar system with hysteresis band controller for inverter

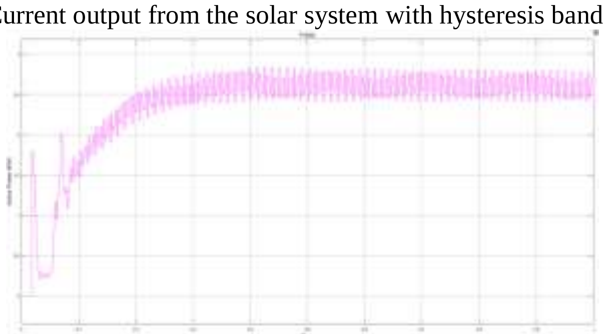

Figure 13 Active power output from the solar system with hysteresis band controller for inverter

Case 2: System with AI based PSO regulatory Fuzzy controller for inverter

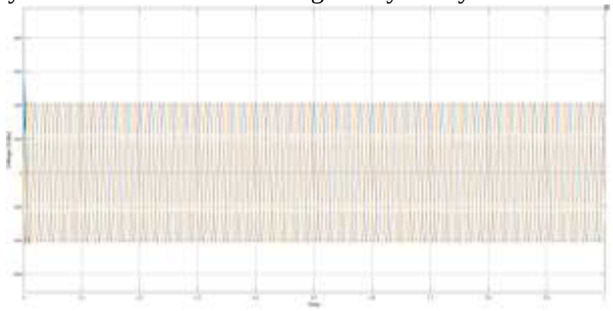

Figure 14 Voltage output from the System with AI based PSO regulatory Fuzzy controller

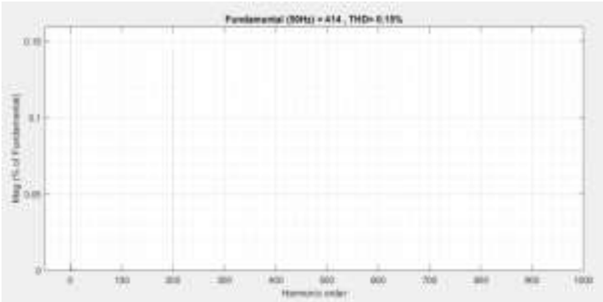

Figure 15 THD% of voltage output from the System with AI based PSO regulatory Fuzzy controller

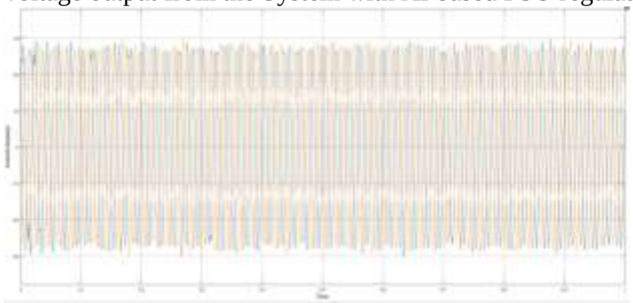

Figure 16 Current output from the System with AI based PSO regulatory Fuzzy controller

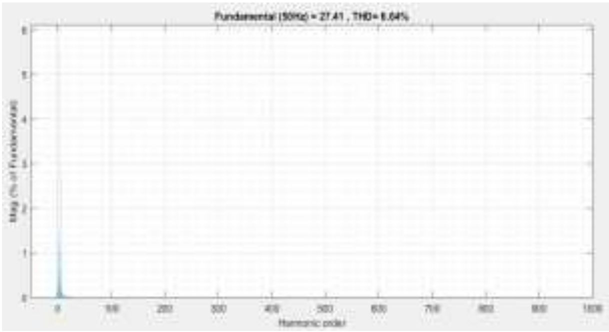

Figure 17 THD% of current output from the System with AI based PSO regulatory Fuzzy controller

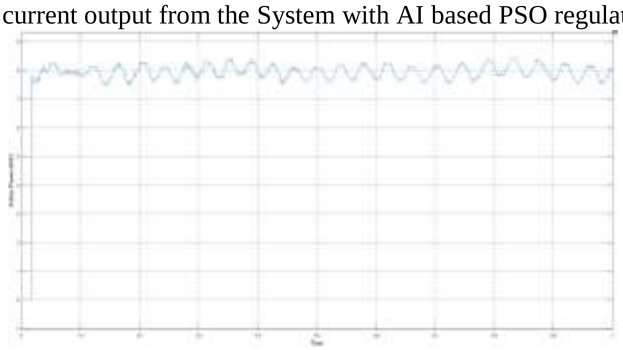

Figure 18 Active Power output from the System with AI based PSO regulatory Fuzzy controller

VI. VALIDATION

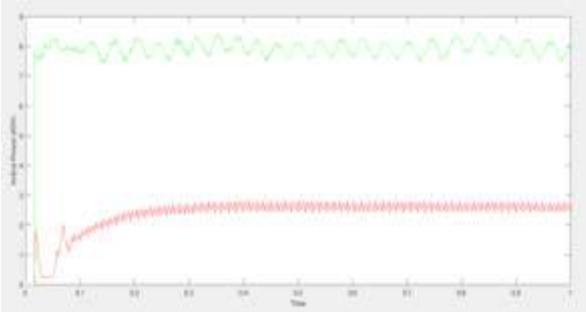

Figure 19 Comparative analysis of active power outputs from the two systems

The figure 19 shows that the active power output from the system having basic hysteresis band inverter control is found to be 3KW and then from the proposed converter it was improved to 8 KW output. Hence it can be concluded that the proposed inverter has reduced the complexity of the system along with an improvement in the power output**.**

Further the work has discussed the total harmonic distortion in the voltage and current output from the systems as well. The proposed work has witnessed a reduction in distortion level as well which concludes the efficiency of the system in all aspects.

VII. CONCLUSION

For on-grid solar power systems, the building is fed from both local grid and a PV array in order to cover the consumer's own power demand and decrease electricity bills. The PV panels are connected with a grid tie inverter that directly converts DC power into AC power. For micro inverters, each PV panel has its own small size inverter, which achieves optimal power conversion for each PV panel. For these inverters, if any PV panel is shaded or is not completely pointed to the sun, the total DC power is not highly affected.

This work provides a comprehensive design and implementation of three-phase Universal Bridge inverter for three phase in a PV – wind hybrid system controlled. The Inverter has been provided with proposed pulse width modulation Technique while integrating it with the grid. The system designed with this as seen considerable improvement in active power output from the system from approximately 3KW in conventional inverter to 8KW in the proposed scheme.

- The voltage output is taken for FFT analysis and THD is calculated. It was found that the proposed work has reduced the distortion in the output voltage being fed to the grid from 0.45% to 0.15%. The same is found true for current output also.

- The proposed system is also integrated with the wind energy system before its integration with grid to make the system more reliable. The system voltage is maintained constant to be 400 Volts

VIII. FUTURE SCOPE

By connecting the super capacitor to the link of an inverter the converter can be designed for a higher voltage and a topology with transformer has to be used. Also, the inverter control can be improved employing certain changes in the boost converter such that it can handle balanced and unbalanced DC voltages.

The work can be expanded to improve the quality of the network powered by renewable energy sources. By improving the signal quality of the output voltage, it can be further integrated into the network.

The modulation technique is simple and easy to implement. Using real facts can make the systems more robust and easier. With the advent of more powerful AI techniques, the computational complexity and the memory usage needs of the algorithms will decrease and more sophisticated and efficient algorithms can be implemented. It is therefore certainly true that the field of adaptive filtering will remain a long-open field for scientific research and commercial applications.

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