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ANALYSIS AND PERFORMANCE ENHANCEMENT OF GRID CONNECTED HYBRID SYSTEM FOR EFFECTIVE POWER TRANSFER

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Abstract — *A new topology and effective power transfer scheme with minimum number of converters is proposed for a grid connected wind/photovoltaic (PV) system. Distributed generation sources considered are permanent magnet synchronous generator (PMSG)-based wind energy conversion system and PV array system. Two voltage source converters with a common DC-link serve as wind side converter (WSC) and grid side converter (GSC), respectively. The Perturb and Observe technique extracts the maximum power from PV and the DC-link voltage is set to the maximum power point (MPP) voltage of the PV array. The output DC voltage of WSC is regulated to an MPP PV voltage using an outer proportional–integral voltage control loop. The maximum power from the PMSG and stator voltages is utilized to generate the reference currents for WSC to make stator currents to follow stator voltages. With unity power factor control, the overall VA of the WSC would contribute to the active power transfer and thereby reduce the kVA rating of the WSC in the proposed configuration. GSC tracks the maximum power from wind and PV array, and serves as a shunt active power filter to compensate for the current unbalance due to the connection of non-linear loads at the grid. The THD value of the system is being compared by using hysteresis and fuzzy logic controller*

Keywords- *PI Controller, PID Controller, Hysteresis, Fuzzy Logic Controller, Total Harmonic*

1. INTRODUCTION

A grid connected system is an electricity generating system that is connected to the utility grid. The grid uses non-conventional energy to reduce the pollution and to perform with better efficiency. We entitle non-conventional energy like photovoltaic or wind energy for wind side and grid side converters. Comparison of THD values by considering the performance of hysteresis and fuzzy logic controller. The GSC and for configuration MOSFET switches is used. Hysteresis is the dependence of the state of a system on its history, the hysteresis loop is formed when electrical displacement field of a ferroelectric material as the electric field is first decreased then increased. Fuzzy logic is a form of many valued logic in which the truth values of variables may be any real number between 0 & 1. It was introduced in 1965. For PV panel, maximum power point tracking technique is used.

1.1 Fuzzy Logic Controller

Fuzzy logic is a form of many valued logic in which the truth values of variables may be any real number between 0 & 1. It was introduced in 1965. It was employed to handle the concept of partial truth, where the truth value may be ranged between completely true or false. The basic block diagram of fuzzy is given which mainly consist of three blocks which are Defuzzifier, Decision rules, Fuzzifier. The inputs are measured quantities which is converted into fuzzy inputs by the fuzzifier. The decision rule block is based on upon a set of if-then rules, which h enables the FLC to take intelligent decisions.

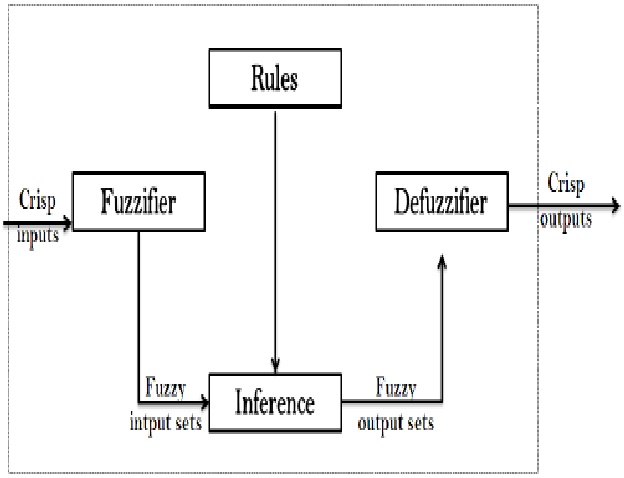

Fig.1: Block diagram of FLC

The defuzzifier block converts the control output generated by the decision rule in to the numerical value. Commonly used technique is center of gravity. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence. Different methods are used like center of area, fuzzy mean etc.

Advantages of Fuzzy Controller

1. It is cheap compared to other conventional controllers
2. It does not require a prior mathematical model.
3. It reduces the switching losses
4. It reduces the total harmonic distortion compared to others

1.2 Hysteresis Controller

In control theory, a bang-bang controller (2 step or on-off controller), also known as a hysteresis controller, is a feedback controller that switches abruptly between two states. These controllers may be realized in terms of any element that provide hysteresis. They are often used to control a plant that accepts a binary input, for example a furnace that is either completely off. Most common residential thermostats are bang-bang controllers. The Heaviside step function in its discrete form is an example of a bang-bang control signal. Due to the discontinuous signal, systems that include bang-bang controllers are variable structure systems, and bang-bang controllers are thus variable structure controllers.

1.3 ANFIS

The acronym ANFIS derives its name from *adaptive neuro-fuzzy inference system*. Using a given input/output data set, the toolbox function anis constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back-propagation algorithm alone or in combination with a least squares type of method. This adjustment allows your fuzzy systems to learn from the data they are modelling.

1.3.1 FIS Structure and Parameter Adjustment

A network-type structure similar to that of a neural network, which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs, can be used to interpret the input/output map. The parameters associated with the membership functions changes through the learning process. The computation of these parameters (or their adjustment) is facilitated by a gradient vector. This gradient vector provides a measure of how well the fuzzy inference system is modelling the input/output data for a given set of parameters. When the gradient vector is obtained, any of several optimization routines can be applied to adjust the parameters to reduce some error measure. This error measure is usually defined by the sum of the squared difference between actual and desired outputs. Anfis uses either back propagation or a combination of least squares estimation and back propagation for membership function parameter estimation.

1.3.4 Use Neuro-Adaptive Learning

The basic structure of fuzzy inference system is a model that maps input characteristics to input membership functions, input membership functions to rules, rules to a set of output characteristics, output characteristics to output membership functions, and the output membership functions to a single-valued output or a decision associated with the output. Such a system uses fixed membership functions that are chosen arbitrarily and a rule structure that is essentially predetermined by the user's interpretation of the characteristics of the variables in the model.

Anfis and the Neuro-Fuzzy Designer apply fuzzy inference techniques to data modelling. As you have seen from the other fuzzy inference GUIs, the shape of the membership functions depends on parameters, and changing these parameters change the shape of the membership function. Instead of just looking at the data to choose the membership function parameters, choose membership function parameters automatically using these Fuzzy Logic Toolbox applications.

Suppose want to apply fuzzy inference to a system for which already have a collection of input/output data that you would like to use for modelling, model-following.

In some modelling situations, you cannot discern what the membership functions should look like simply from looking at data. Rather than choosing the parameters associated with a given membership function arbitrarily, these parameters could be chosen so as to tailor the membership functions to the input/output data in order to account for these types of variations in the data values.

1.4 PI Controller

The PID controller consists of three separate branches - proportional, integral and derivative. The three terms of the controller serve to respond to different elements of the error signal, with the proportional part acting immediately on the current error, the integral adding a contribution equivalent to the history of all errors and the derivative action predicting the future contribution of the errors. The addition of the integral and derivative actions to the basic proportional element enhances the performance of the controller by reducing steady state errors and the rise/fall times respectively.

A popular variation of the PID algorithm is the PI algorithm, which features only the proportional and derivative terms. Elimination of the derivative term in the algorithm results in increased noise immunity, making it a popular and widely used variant of the classic PID.

1.5 PID Controller

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is

$$u(t) = \mathrm{MV}(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de(t)}{dt},$$

Where,

Kp is the proportional gain, a tuning parameter,

Kd is the integral gain, a tuning parameter,

Ki is the derivative gain, a tuning parameter,
e(t) is the error (SP is the setpoint, and PV(*t*) is the process variable),

t is the time or instantaneous time (the present)

1.5.1 Limitation of PID controller

While PID controllers are applicable to many control problems, and often perform satisfactorily without any improvements or only coarse tuning, they can perform poorly in some applications, and do not in general provide optimal control. The fundamental difficulty with PID control is that it is a feedback control system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise. While PID control is the best controller in an observer without a model of the process, better performance can be obtained by overtly modelling the actor of the process without resorting to an observer.

PID controllers, when used alone, can give mediocre performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control setpoint value. They also have difficulties in the presence of non-linearities, may trade-off regulation versus response time, do not react to changing process behavior (say, the process changes after it has warmed up), and have lag in responding to large disturbances.

The most significant improvement is to incorporate feed-forward control with knowledge about the system and using the PID only to control error. Alternatively, PIDs can be modified in more minor ways, such as by changing the parameters (either gain scheduling in different use cases or adaptively modifying them based on performance), improving measurement (higher sampling rate, precision, and accuracy, and low-pass filtering if necessary), or cascading multiple PID controllers.

Table 1: System parameters

Parameters	**Hysteresis**	**FLC**
Wind Speed	12 m/s	12 m/s
Pitch Angle	1 Degree	1 Degree
Wind Output Voltage	410 V	460 V
Wind Output Current	9.2 A	9.2 A
Switching Frequency	20 k z	1 k z
Irradiation	3000W/m^2	3000W/m^2

Solar Output Voltage	228 V	228 V
Solar Output Current	14.25 A	14.25 A
Total Harmonic Distortion	5.66%	1.44%
Load Side Voltage	450 V	460 V
Load Side Current	9.32 A	9.2 A
Input grid Voltage	500 V	500 V
MOSFET internal FET Resistor	0.1 R	0.1 R
MOSFET internal diode Resistor	0.01 R	0.01R
Reference Voltage in FLC	-	1500 V
I – d axis for Current Controller	500 A	-

2. PROPOSED SYSTEM

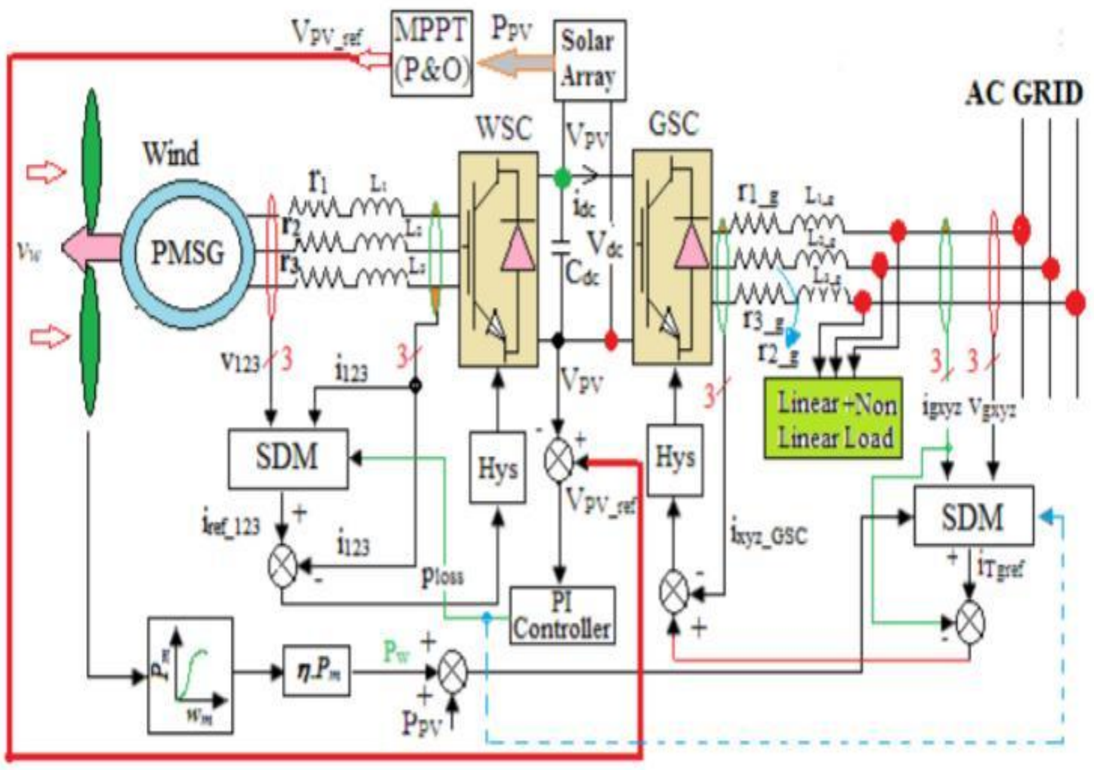

Fig.2: Layout of proposed system

A WSC is connected to the stator of PMSG and GSC transfers power from the DG sources to the grid. Both WSC and GSC are bidirectional voltage source converters connected in back-to-back configuration through a common DC link. The PV array is tied to the DC bus creating a variable DC-link voltage. To facilitate power extraction from both PV array and wind, the GSC is current controlled to deliver maximum power from both renewable. A PI voltage controller takes care of servo changes in the voltage loop of WSC with respect to the PV voltage. In this proposed scheme, the DC voltage reference for the WSC is set to the MPP voltage of the PV panel. In the absence of solar energy, the reference DC voltage of WSC is set to a default value.

3. EXISTING SYSTEM

A new topology and effective power transfer scheme with minimum number of converters is proposed for a grid connected wind/photovoltaic (PV) system. Distributed generation sources considered are permanent magnet synchronous generator (PMSG)-based wind energy conversion system and PV array system. Two voltage source converters with a common DC-link serve as wind side converter (WSC) and grid side converter (GSC), respectively. The PV array is directly tied to the DC link without any power converter providing variable DC-link voltage. The Perturb and Observe technique extracts the maximum power from PV and the DC-link voltage is set to the maximum power point (MPP) voltage of the PV array. The output DC voltage of WSC is regulated to an MPP PV voltage using an outer proportional–integral voltage control loop. The maximum power from the PMSG and stator voltages is utilised to generate the reference currents for WSC to make stator currents to follow stator voltages. With unity power factor control, the overall VA of the WSC would contribute to the active power transfer and thereby reduce the kVA rating of the WSC in the proposed configuration. GSC tracks the maximum power from wind and PV array, and serves as a shunt active power filter to compensate for the current unbalance due to the connection of non-linear loads at the grid. All these functions are accomplished simultaneously. Various power transfer modes of operation are simulated through MATLAB/Simulink

3. SYSTEM DESCRIPTION

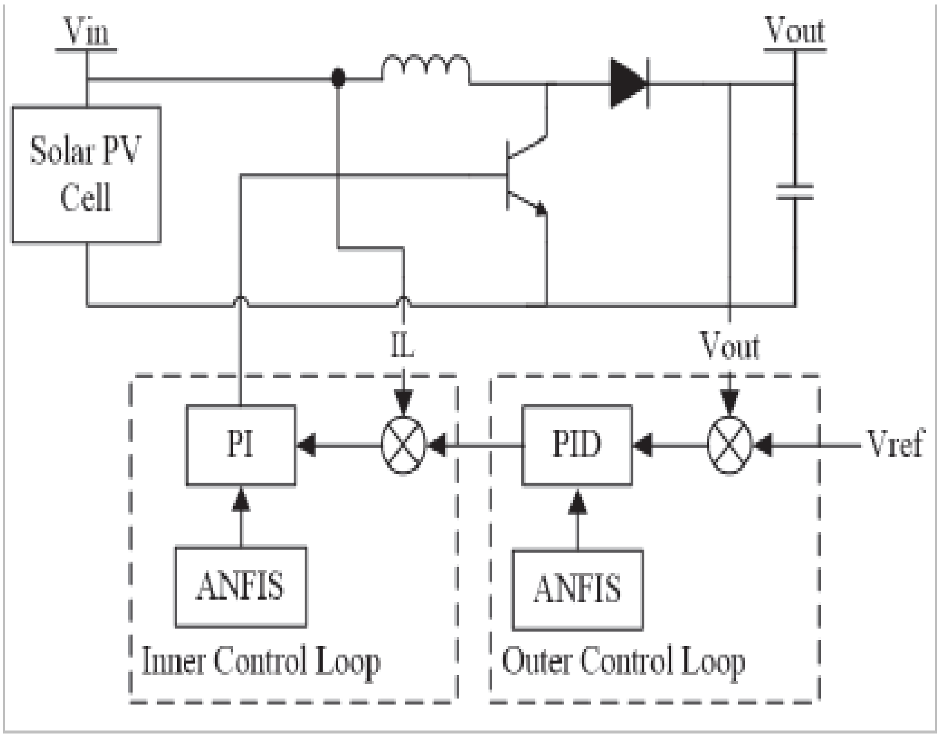

Fig 3: Block Diagram

The main goal of the system presented in this paper is to create a stable VDC power supply from a solar PV cell. The output of the solar cell is applied firstly to a pre-regulator, which is used to apply a MPPT algorithm, and finally to a boost converter to provide the stable output. The main interest of this paper is the control of the boost converter, which features the novel Adaptive Neuro-Fuzzy Inference System -PI control solution. A diagram of the full circuit is given in Fig 1, showing the PV cell, the boost converter and a pair of Adaptive Neuro-Fuzzy Inference System-PI controllers.

As shown in Figure below, there are two PI controllers in the system - the inner PI controls the inductor current whilst the other controls the output voltage. The inner PI controller is shown by the bounded area labelled inner control loop and the outer loop is labelled outer control loop. Whilst Fuzzy logic and Neural Networks are both well-established AI techniques which have been widely applied to the field of control, both have drawbacks. In the case of fuzzy logic, whilst it is excellent at making decisions, the major drawback is the inability to learn. Conversely, neural networks don't share this ability to make decisions but do possess the ability to learn. Combining the benefits of both types of system, new hybrid Neuro-Fuzzy systems have emerged.

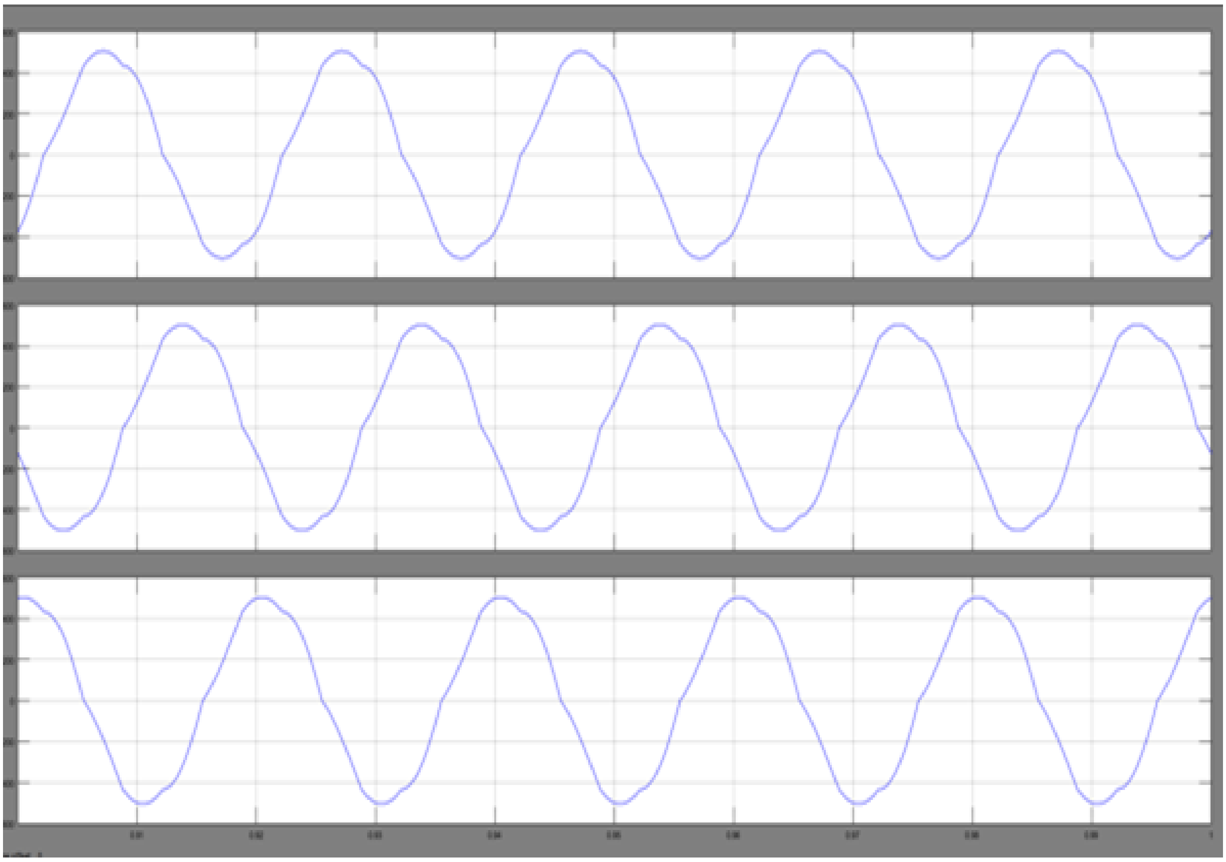

Fig 4: Input Waveform

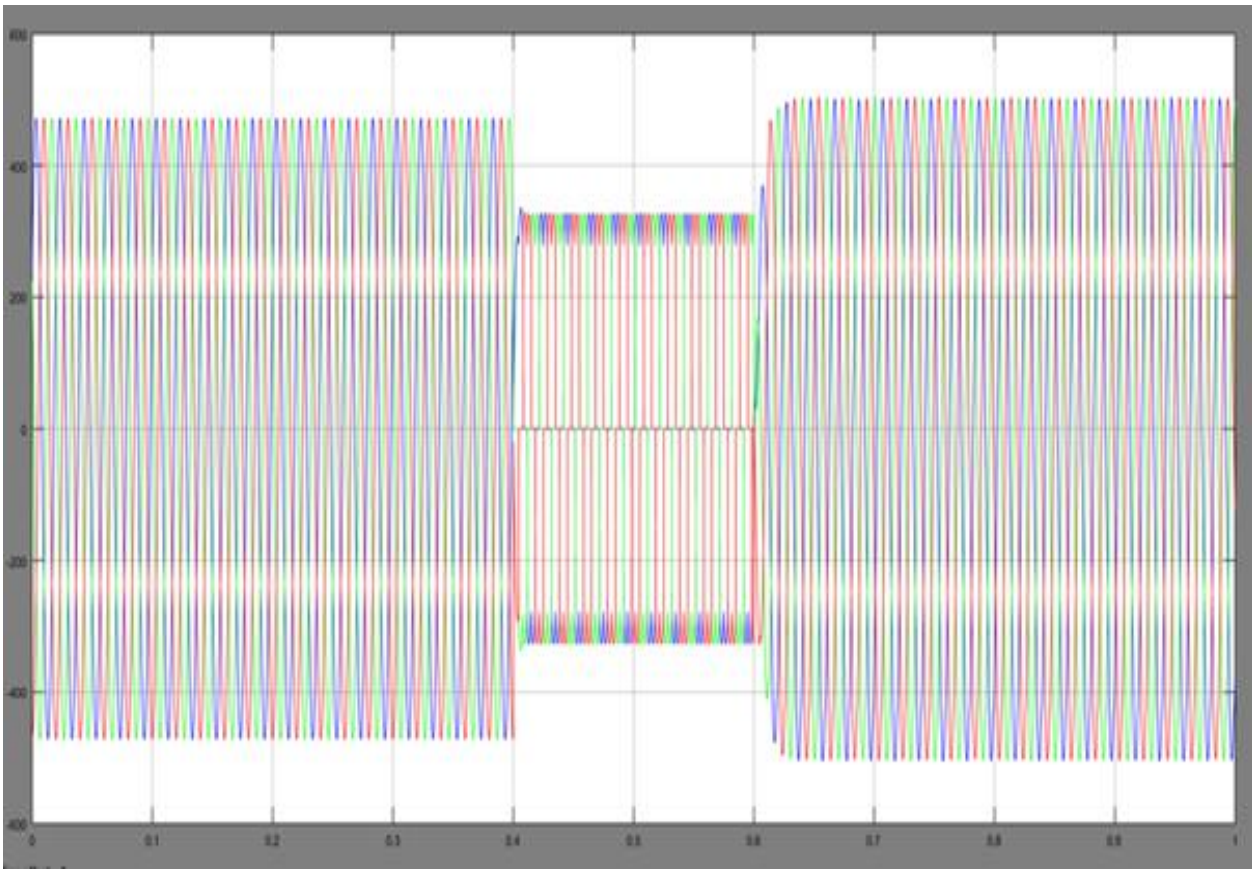

Fig 5: Output Voltage with Hysteresis =460 V

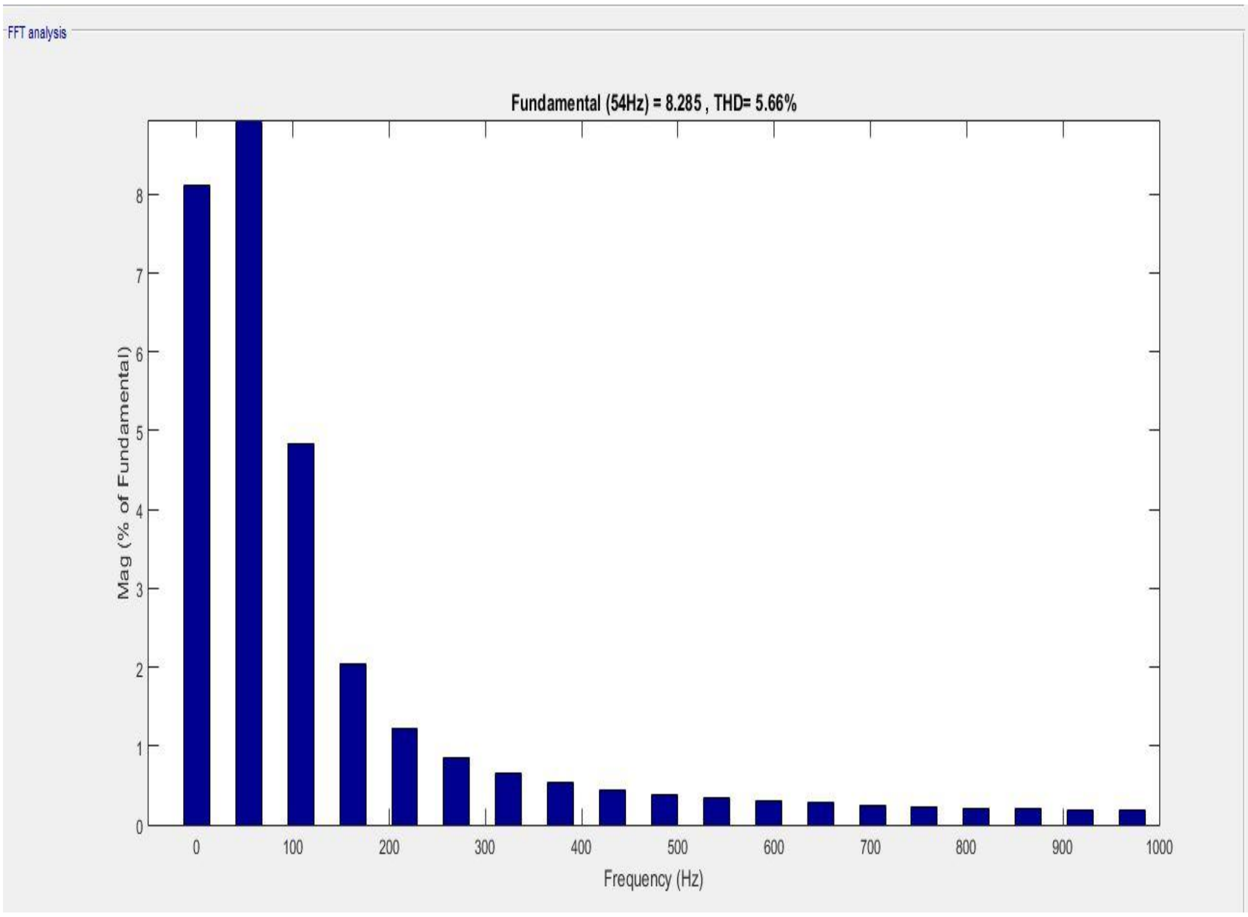

Fig 6: THD Value Hysteresis

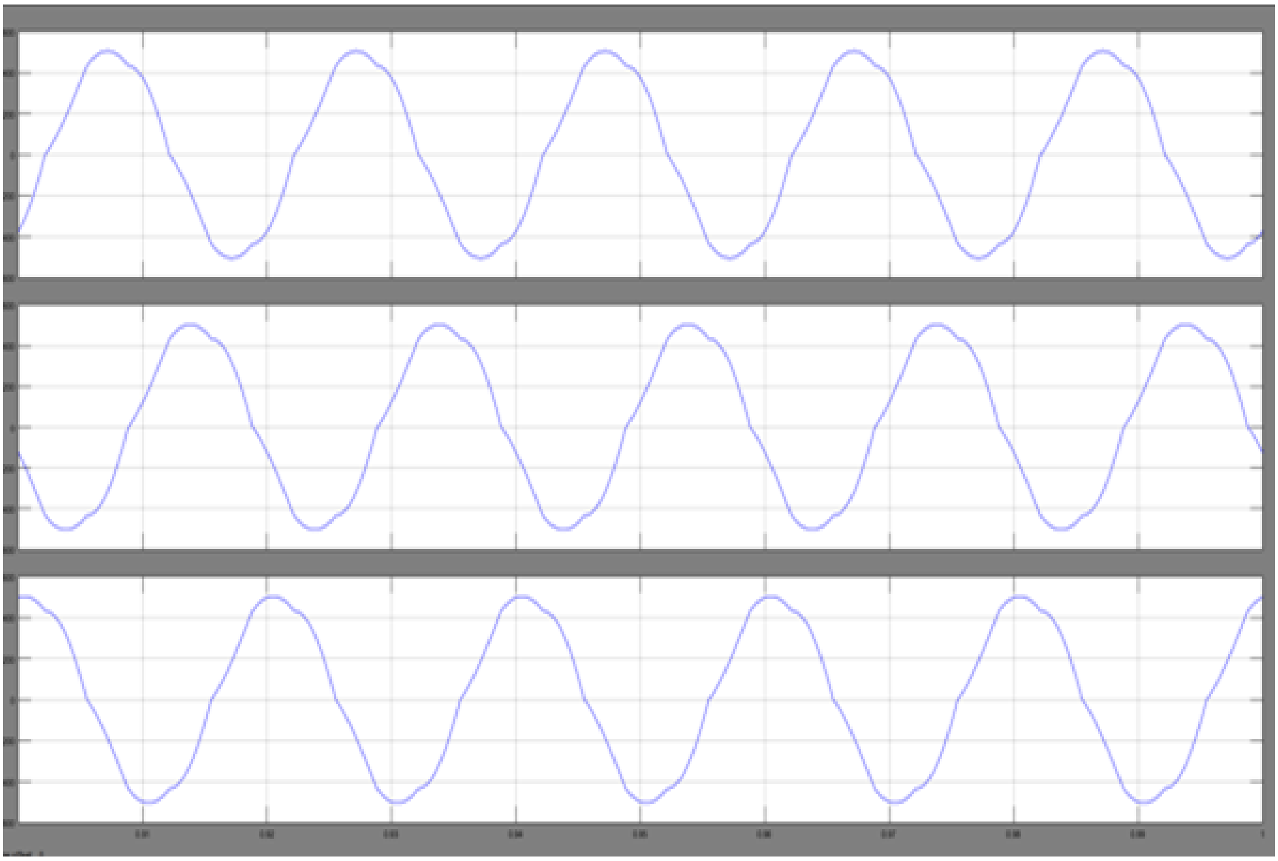

Fig 7: Input Waveform

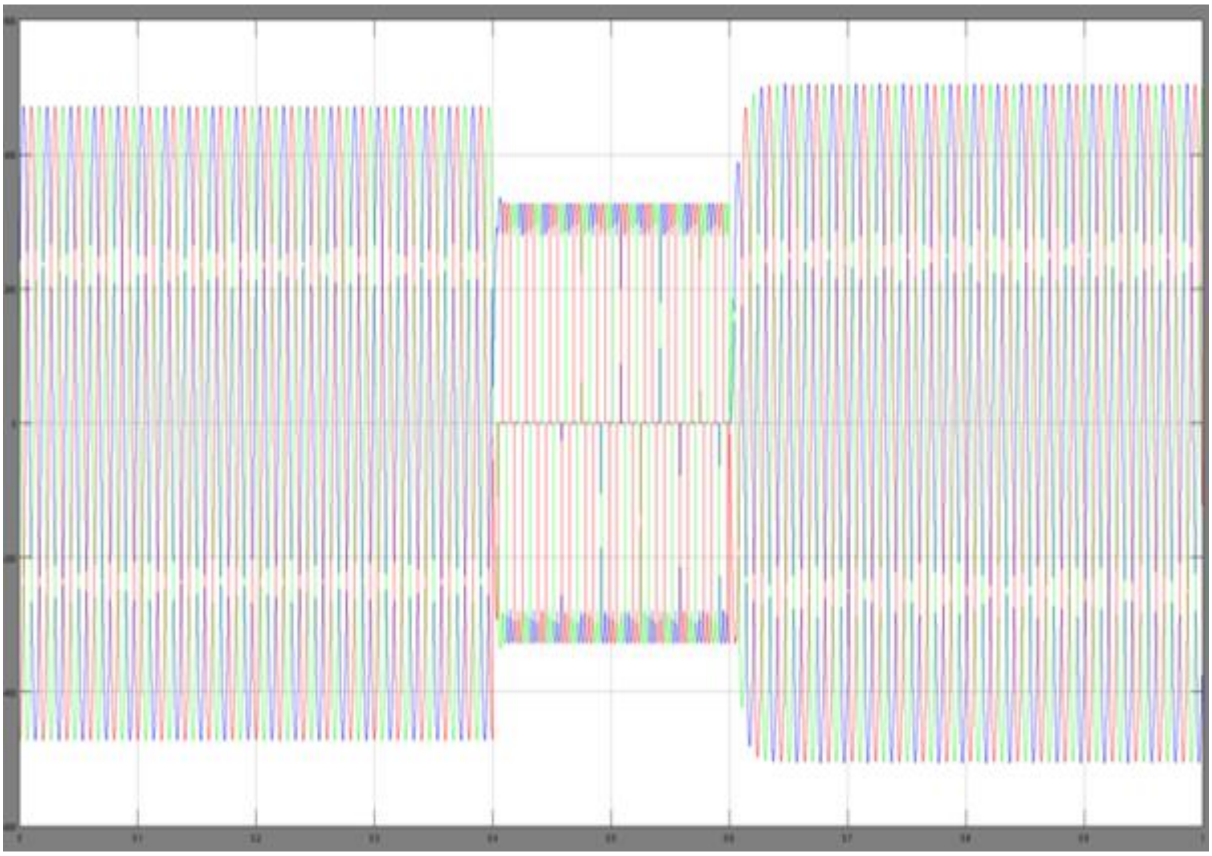

Fig 8: Input Waveform

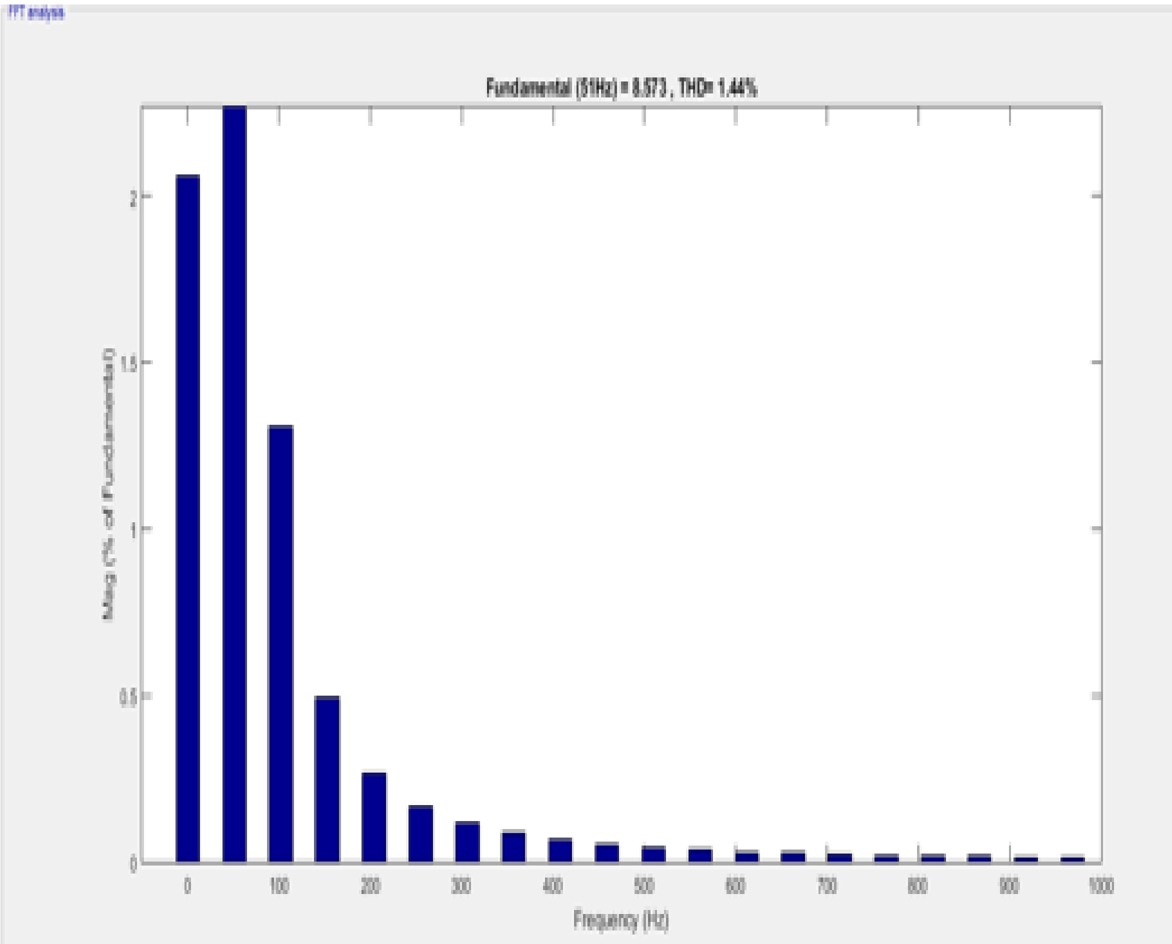

Fig 9: THD Value of fuzzy logic controller

5. RESULTS AND DISCUSSION

The system consists of using two back-to-back interfaced converters with a common DC link where the PV panel is directly tied. The MPP algorithm is implemented on both WECS and PV panel to extract the maximum power under any conditions of atmospheric wind and solar irradiation, respectively. The control strategy for WSC consists of DC-link voltage regulation using PI controller and effective power transfer from PMSG using HC. The control strategy for GSC consists of transferring the maximum available wind and solar power to the linear/non-linear loads and grid using HC. The proposed system cab be validated on a scaled hardware prototype implemented using DS1104 DSP of dSPACE. The experimental results are found to complement the simulation results under both steady state transient conditions.

Steady-state investigations are conducted at a constant wind speed of 12 m/s and under constant irradiation of 1000 W/m2. The implemented (P&O) MPP algorithm for PV panel successfully tracks the maximum power and outputs the corresponding MPP voltage as a reference to the comparator for DC-link voltage regulation. The current controller of both WSC and GSC operates to effectively transfer the available maximum renewable power to the load/grid, which can be validated from the results shown in Figures show the scaled down sinusoidal compensated WSC currents and WSC voltages under constant wind speed of 12 m/s, respectively. Fig. 9*b* implies UPF operation of WSC under rectification mode with power being transferred from PMSG to the DC side from these experimental results. It can be seen that the WSC currents, with reduced harmonics follows WSC voltages complementing the simulation results. Figs. 9*c* and *d* show the utility grid voltage and scaled down GSC compensated grid currents at UPF operation. Here the DC power is transferred to linear/non-linear loads with surplus power being fed to the grid through GSC, operating under inversion mode. It can be explicitly seen that the overall VA of GSC takes part in transferring actual power to the grid with GSC currents in phase with GSC voltages. The system is investigated for step changes in wind speed and solar irradiation and the results are verified for successful operation of the control scheme. Fig. 10*a* shows at a constant wind speed of 12 m/s, a step decrease in PV MPP voltage is applied by changing the irradiation from 1000 to 800 W/m2. The PI controller reacts quickly for this change and effectively regulates the DC-link voltage to the corresponding reference voltage. Fig. 10*b* shows a constant irradiation of 1000 W/m2, and a step increase in wind speed is applied from 10 to 12 m/s. The HC of WSC quickly transfers this increased wind generated power to the DC link which can be verified with the increased WSC currents as shown in Figure. The results for variations of wind speed and PV voltage are given in figures illustrates the variations in GSC compensated grid currents with variations in solar MPP voltage. The DC-link voltage gets regulated corresponding to changes in solar MPP voltage and the GSC currents decreases with a reduction in the DC-link voltage. Fig. 10*b* shows the variations in WSC compensated currents corresponding to wind velocity variations for a wind speed change from 10 to 12 m/s. It can be seen that the WSC currents increases with an increase in wind speed from 10 to 12 m/s. Figures show the zoomed in view of the sinusoidal compensated WSC and GSCcurrents, respectively.

6.0 CONCLUSION

This paper presents a hybrid DG system comprising of PMSG based WECS and PV array system interfaced through a common DC link. With parallel operation of PMSG and PV, future expansion of the system becomes feasible allowing plug and play, load sharing and islanded mode of operation. The DC voltage is regulated to an MPP voltage of PV through WSC. Without involving any DC–DC converter and duty cycle variation and with fewer power converters employed, the system extracts maximum power from PMSG and PV and transfers it to linear/non-linear loads and grid through a GSC. Same VSC topology and controls is implemented in both WSC and GSC to achieve maximum power transfer under various sources and load conditions. The proposed system may facilitate the integration process of DC power technologies into the existing AC system. Maximum power from PMSG is used to generate reference currents for WSC to control the harmonics in PMSG stator currents leading to better utilization of PMSG. GSC acts as a STATCOM providing VAR support to the grid connected loads and simultaneously transfers active power to the grid. The system is simulated in MATLAB/SIMULINK.

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