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Super Capacitor-based Inverter control using Fuzzy Controller Wind Energy System connected to Weak Grid

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Abstract**: *In this article, a fuzzy based inverter control is applied to a weak grid connected wind energy system. Whenever Wind Energy system connected to battery storage or super capacitor, which is nothing but a Hybrid Energy System (HES). These Wind HES are sometimes subjected to transients and gives sluggish dynamic output as the wind speed varies and moreover the generator inertia doesn't allow quick rotation when wind is blown to turbine. So, these transients and dynamic results are modified using the fuzzy based inverter control technique. This controlling technique brings a Super-Capacitor (SC) quick charging/discharging features for buck-boost converter. The transient behavior and the frequency response of the system is improved with buck–boost converter that conducts bi-directionally. Fuzzy Logic Controller (FLC) used in the control technique produces the controlled reference output required for the inverter operation. Fuzzy based inverter control scheme designed and analyzed under the weak grid condition. The new control method used for weak grid/load like marine electrical system, this wind energy system decreases the fossil fuels use and the entire proposing work is to be analyzed in MATLAB Simulink environment. The outcomes are presented and compared to the traditional control technique to justify the reduced the oscillations and improvement in the quality of power.***

Keywords**: *Hybrid Energy System (HES), Super Capacitor (SC), Fuzzy Logic Controller (FLC), PCC (Point of Common Coupling) and Insulated Gate Bipolar Transistor (IGBT)***

I. INTRODUCTION

Lack of energy in this world is the major concern because of rapid depletion of fossil fuels, which is used for the production of electrical power. As the conventional energy sources consume lot of fossil fuel for generation, so there is lot of wastage and also causes environmental pollution as they release gases in the air.So, to increase the energy by non-conventional energy sources, there are so many renewable energy sources are evolved and innovated which produce additional power without causing any pollution to the environment and supplying quality power. The wind energy system is more viable option out of the existing renewable energy methods, reliable and can be installed near availability of wind like coastal areas and hilly areas. In wind power generation there are few difficulties in the generating power because the wind turbines become unstable as the wind turbine shafted to generator is subjected to sudden changes and the initial rotation is lagged because of the inertia of generator. The proposed a fuzzy logic controller connected to a weak grid, to improve the system dynamic response and the quality of power. The wind energy is the best options out of the existing renewable energy sources because power can be generated small to medium range. In [1] the author tried to minimize the harmonics by using dual inverter-based controller. In [2] oscillations are damped out small range by using droop controller. In [3] under high speed wind is taken to control the turbine and improve the response of the system. In [4] the author little improve the dynamic and transient's response by using the SC and battery control. In [5] PMSG produces more ripples, so blocking these ripples to introduces the DC-link capacitor and improve the current and torque quality. In [6] introduced wind-based HES to improve the little efficiency stability of the wind system. In [7] the arrangement of SC and buck-boost converter tried to improve the frequency and dynamic response but not reduces oscillations, no improvement in the power quality. So, in this introduced fuzzy logic controller (FLC) to reduce the oscillations, improve the frequency response and quality of power. Finally strengthen the weak grid as soon as possible.

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II. SYSTEM DESIGN

In this paper HES connected to a weak grid, in this control technique to address the problems when connected to HES. This energy system connected to either grid or standalone for required utilization of different conditions. The wind speed not able to predicted and inertia of the generator system does not change quickly its takes time to respond, that's why want a dc link voltage connected across the system to maintain the constant voltage, so by using the DC link capacitor and super capacitor based buck-boost converter maintains constant voltage. But having some oscillations and slow dynamic response and low power quality. So, the proposed control scheme introduces the Fuzzy Logic Controller (FLC)

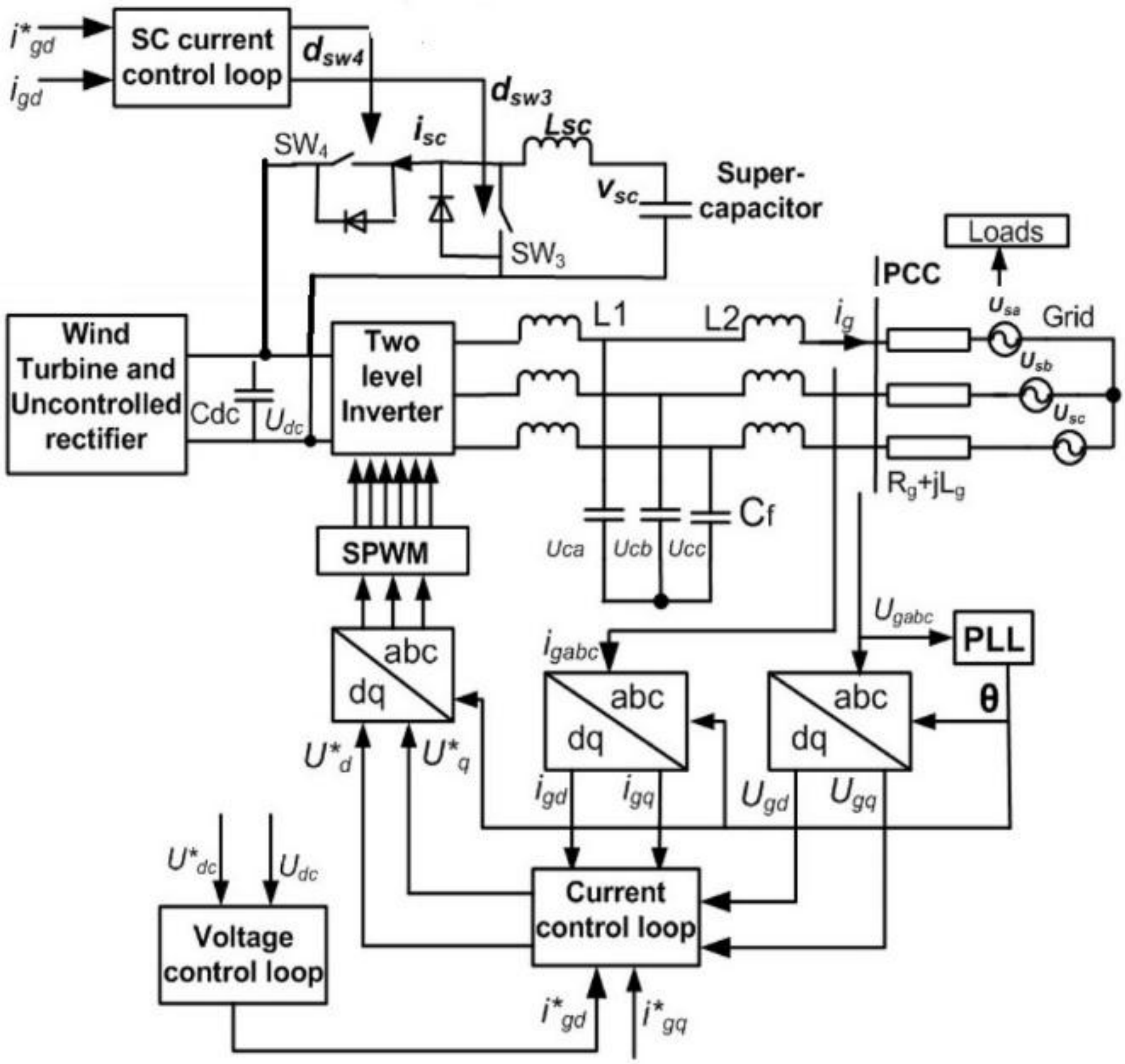


Fig.1. Block Diagram of HES connected to a grid

to overcome the problems and enhance the power quality and stability of the system.

The conventional block diagram fig (1) shows the total arrangement of wind-based hybrid energy system, the wind turbine generator set connected to diode rectifier (uncontrolled rectifier), both shows in one block. DC-link super capacitor-based buck-boost converter connected between the diode rectifier and two-level inverter controller. Inverter controller generates the harmonics so to suppress the harmonics by using L-C-L filter (inductance -capacitance-inductance), the L-C-L filter values taken depends upon the rating of the system, in figure having L1, L2 are inductance values and C_f is capacitance value. Where i_{gabc} is a grid current, U_{sabc} is 3-phase grid voltage, U_{gabc} is the 3-phase voltage at Point of Common Coupling(PCC), $R_g + jL_g$ is the grid impedance.

Whenever wind energy system connected to battery storage or super capacitor which is nothing but hybrid system. In this battery storage having the super capacitor-based buck-boost converter, the advantage of super capacitor is fast charging and discharging time. In buck-boost converter using Insulated Gate Bipolar Transistor (IGBT) switches to generates the duty cycles. According to the power required, if current is low, boost the current and power is high generated, stored in the super capacitor. Buck-boost converter (DC-DC converter) having IGBT switches SW3 and SW4, dsw3 and dsw4 are the duty cycles of the switches to control the up and down voltage, i_{sc} is the SC current, V_{sc} is the SC voltage.

In this paper **abc/dq** transform is used in 3-phase synchronous machine or 3-phase inverter for simplify the calculations. So, this transformation easy to compare the voltage and current signals. In synchronous reference frame i^*_{gd} and i^*_{gd} are the reference grid currents of d and q-axis respectively. i_{gd} and $i_{gq}$are grid currents of d and q-axis respectively. In similar way, U_{gd} and U_{gq} are grid voltages at the PCC, U_{sd} and U_{sq} are the d and q-axis of grid voltages.

The wind-based hybrid energy system is connected to weak grid to analyses the behavior of waveforms at different conditions like under the over voltage, short circuit, and sudden change load and also analyses the frequency response of the system , the weak grid having low voltage level, short circuit current level is less than 2 MVA, the grid impedance has taken $\frac{X_g}{R_g}$ >3.

III. DETAILED EXAMINATIONS OF THE TRADITIONAL CONTROL TECHNIQUE

In this segment the control technique can be analyses mathematically show in figure (2), in this control scheme can be divided in to two parts to control the reactive power control (current control loop) and DC-link voltage (voltage control loop). The voltage control loop maintains the constant DC-link voltage at any operating conditions. The current control loop regulates the d-axis and q-axis current, from the figure the d-axis reference current is taken for to maintain the DC-link voltage constant and inject the active power to the grid. The q-axis current is set zero to maintain the unity power factor and inject the reactive power to the grid.

Presently, the power adjusting condition for grid associated wind energy framework can be composed as:

$$P_g = \frac{3}{2}\left(U_{gd}i_{gd} + U_{gq}i_{gq}\right) = \frac{3}{2}\left(U_{gd}i_{gd}\right) \quad (1)$$

P_g - Injected power to the grid and i_{gq} = 0.

Wind input power available after the inverter is:

$$P_{inv} = U_{dc}i_{inv} + U_{dc}i_{dc} \quad (2)$$

P_{inv} - Input power, i_{inv} - input current of the inverter i_{dc} - current of DC link capacitor is given as:

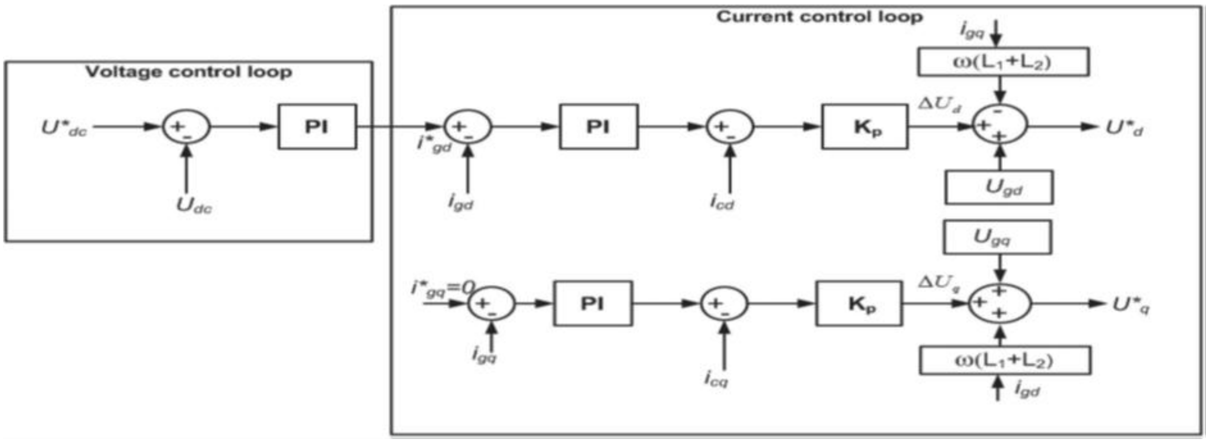


Fig. 2. Traditional control scheme

$$i_{dc} = U_{dc}C_{dc}\frac{dU_{dc}}{dt} \quad (3)$$

If U_{dc} is constant, i_{dc} = 0. So, i_{dc} is the transient current and doesn't exist at steady state,

Therefore, the equation of the of inverter input power,

$$P_{inv} = U_{dc}i_{inv} + U_{dc}C_{dc}\frac{dU_{dc}}{dt} \quad (4)$$

Generally, the input power equal to the output power given below by

$$\frac{3}{2}U_{gd}i_{gd} = U_{dc}i_{inv} + U_{dc}C_{dc}\frac{dU_{dc}}{dt} \quad (5)$$

So, taking reference from Eq. (5) the voltage control system can be constructed, and i^*_{gd} is voltage controller outcome which keeps DC link voltage steady.

Likewise, U_d and U_q (inverter output voltages) can be written as:

$$U_d = L\frac{di_{gd}}{dt} + U_{gd} - \omega L i_{gq} \quad (6)$$

$$U_q = L\frac{di_{gq}}{dt} + U_{gq} + \omega L i_{gd} \quad (7)$$

where, ω = angular frequency,

L = L1 + L2,

To get reference voltages (U^*_d & U^*_q) ΔU is added to the current controller output using feed-forward decoupled control

$$U^*_d = \Delta U_d + U_{gd} - \omega L i_{gq} \quad (8)$$

$$U^*_q = \Delta U_q + U_{gq} + \omega L i_{gd} \quad (9)$$

With the help of Ea.'s (8) and (9), active power and reactive power can be regulated by using the current control loop be that as it may, in the fragile grid, the ordinary control having issues of moderate dynamic reaction, steady state ripples and diminished stability margin can be scientifically broke down as given beneath.

Under different conditions, DC interface voltage is vacillated, which change the reference network current expected to keep up the DC connect voltage steady, in this way, any change in working conditions is straightforwardly reflected into reference flows as

$$i^*_{gd} = \Delta i_{gd} + i_{gd} \quad (10)$$

$$i^*_{gq} = \Delta i_{gq} + i_{gq} \quad (11)$$

where, Δi_{gd} and Δi_{gq} are the estimations of current (can be negative likewise) that get included in the past network current values under different conditions into the base currents.

By replacing the PI controller with the Fuzzy Logic controller, we can get the better outcome and the performance of the system is also improved.

IV. FUZZY CONTROL SYSTEM

Fuzzy Logic Control (FLC)is a super set Boolean logic that has been arranged to manage the standard of partial truth esteems between truth and false it is a sort of logic that separates further the basic true and false values.

Traditional controllers have few limitations are system non-linearity, system vulnerability, system response and transients, oscillations are there, on other hand FLC is more robust, arrangement of FLC is less expensive than model-based controllers for comparable applications.

FLC is simple to execute and has capacity to interpret uncertain and unclear learning of human experts. FLC control technique has easily modify as the control and design process is easy to identify for any applications.

The control work is depending on logic of fuzzy is broadly utilized in machine control. It shows an uncomplicate terms with constant attributes between 0 and 1. The enhanced logic works on discrete estimation of 0 or 1.

The subject suggests the logic of fuzzy as false or true. For an instance, in logic of fuzzy with neural interface system and genetic algorithm are commonly used. Thus, it is easier with an effective performance. Fig shows the block diagram of the FLC. The proposed control of the wind energy system.

The representation of fuzzy control is to be mapped each other in all sets. It is called as fuzzy sets. The process of changing real scalar value into fuzzy value is known as fuzzification. The membership functions of two inputs and one output can shown in figures.

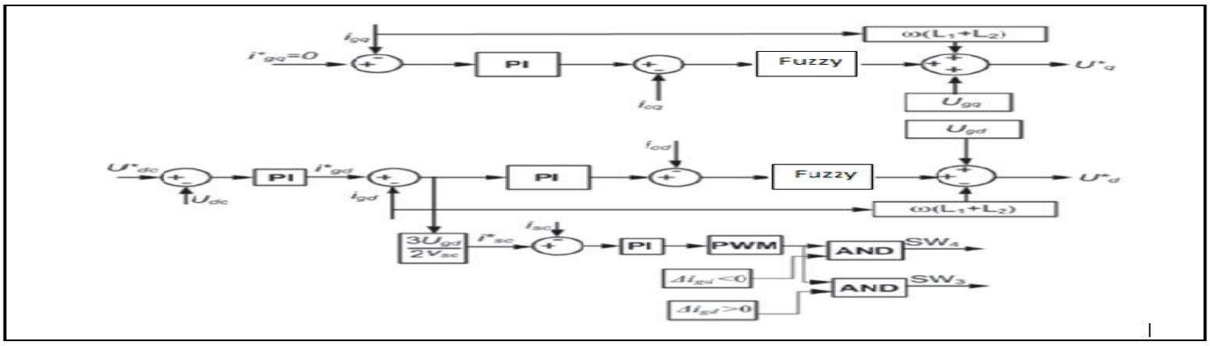
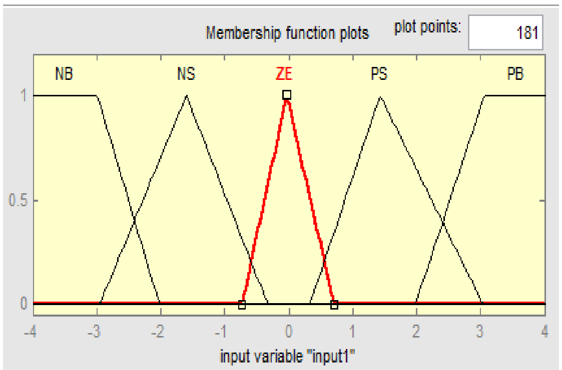
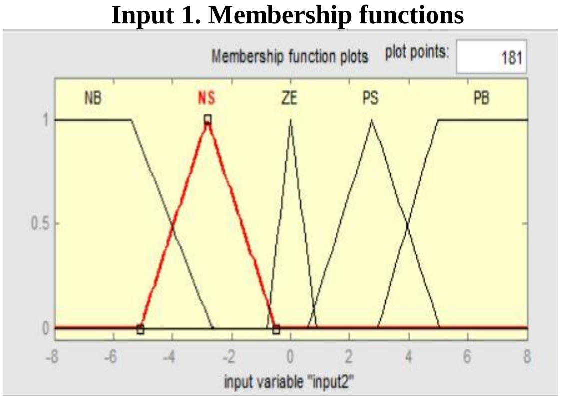


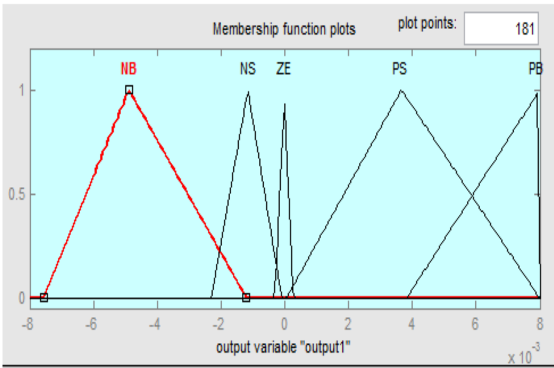
Fig. 3.Proposed control scheme



Input 1. Membership functions



Input 2. Membership Functions



Output Membership Functions

Table 1: fuzzy table

ΔE/E	NB	NS	ZE	PS	PB
NS	ZE	PS	PS	**ZE**	ZS
NB	PB	PS	ZE	ZE	NS
ZE	PB	PS	ZE	NS	NB
PS	PS	ZE	ZE	NS	NB
PB	PS	ZE	NS	NS	ZE

V. SIMULATION DIAGRAM AND RESULTS DISCUSSION

The new control methodology has been executed on a 150 kw. wind energy system decreases the fossil fuels use and the entire proposing work is to be analyzed in MATLAB Simulink environment.

The outcomes are presented and compared to the traditional control technique to justify the reduce the oscillations and improvement in the quality of power The variables of the system are used in the control technique given in table 2 and 3.

Table 2: Storage device parameters

Super capacitor	58f,16v, 20 no.of connected in series
L_{SC}	4mH
V_{SC}	320 V
U_{dc} nominal	450 V
d_{sc}	0.33

Table 3: Nominal system parameters.

Wind power rating	150kw
AC bus voltage rating, V_L	270 V
C_{pv}	100 μF
L_{dc}	3 mH
C_{dc}	1000μF
L_1	0.36 mH
L_2	0.6 mH
C_f	7 μF
X_g/R_g	=< 3
Grid conditions	1 MVA SCC, 50 Hz

Fig 4a. shows the waveform of the wind speed given to the wind turbine, where a change in wind speed is introduced at one second (1s) to show the transient and dynamic behavior of the new control technique as compared with tradition control technique. In fig 4b. power response of the wind scheme corresponding speed, in fig 4c. clearly shows the proposed waveform is much improve steady-state output as compared with traditional control technique. Therefore, the new control technique has better improvement in power quality as compared with traditional control technique.

Fig 5a.demonstrate the waveform of DC-link voltage with new control technique and traditional control technique in which DC-link voltage indicates better improvement of transient and dynamic stability, in fig 5b. and fig 5c. demonstrate the behavior of the DC-voltage with various grid impedances of different Lg values, Lg = 0.05 mH waveform have low oscillations comparing others, so the fuzzy based waveforms much low oscillations comparing with traditional scheme.

Fig 6a. shows the constant voltage irrespective of the change in the wind speed and load. Fig 6b. demonstrate the grid current will be change with respect to wind speed. Fig 6c. demonstrates the phase A grid current and voltage, this waveform analyses favorable control of the reactive power. Current and voltage waveforms are in phase i.e., unit power factor injected power because q-axis reference current is taken has zero.

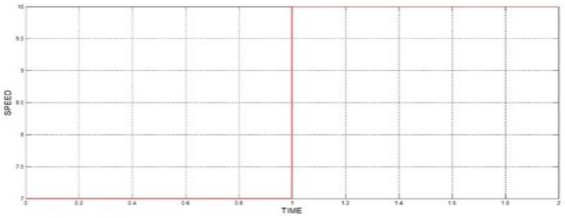
Fig 7a. waveform demonstrates under fault condition, the RMS AC voltage much better comparing with traditional control scheme.

Fig 7b. shows the DC-link current under different conditions under over voltages, short circuit, and sudden changed load.

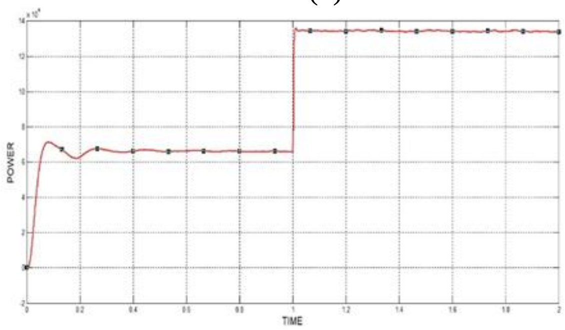
Fig 7c. the frequency response of the proposed scheme is much better response comparing with traditional scheme.

Finally, comparison between PI and Fuzzy controller as shown in table 4.

(a)



(b)



(C)

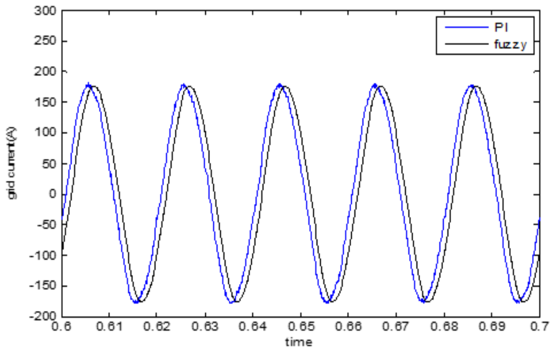
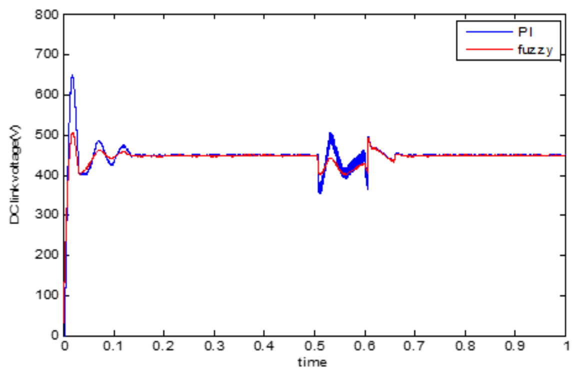
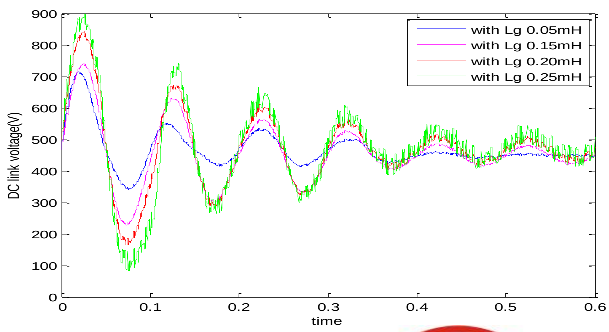


Fig.4.Waveforms of (a) wind speed, (b) wind power and (c) grid current

(a)



(b)



(c)

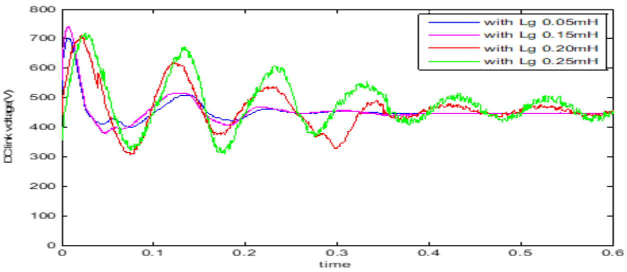
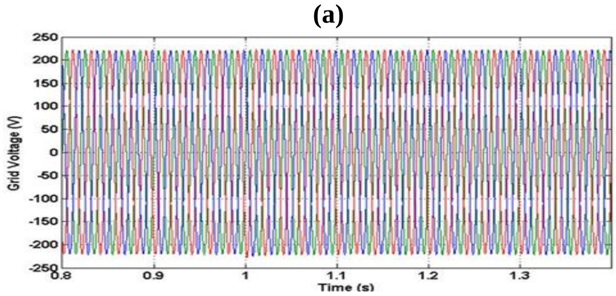
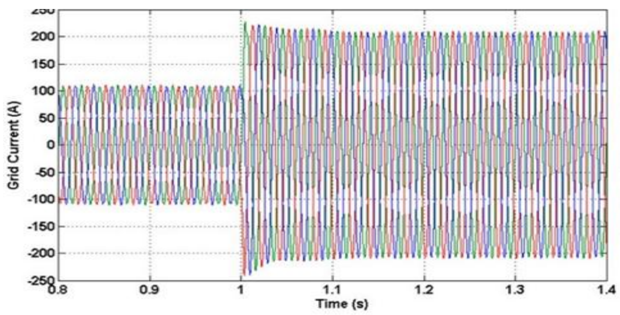


Fig. 5. Waveforms of DC link voltage (a) under transients conditions, (b) under different Lg with the traditional control technique and (c) under different Lg with the new control technique

(a)



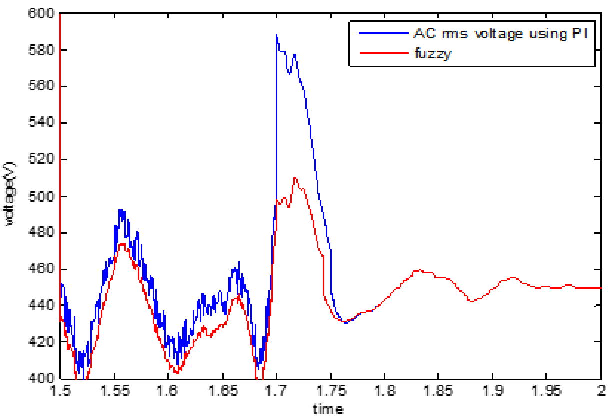
(b)



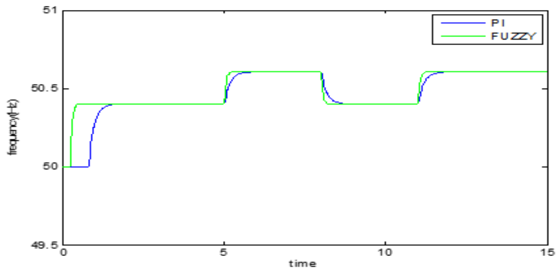
(c)

Fig. 6. Waveforms of (a) grid voltage, (b) grid current and(c) phase A grid current and voltage

(a)



(b)



(c)

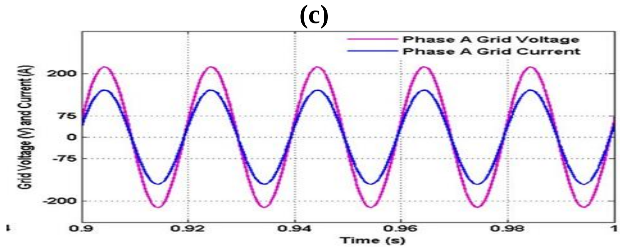


Fig 7. Waveforms of (a)AC voltage under different conditions, (b) DC link voltage and (c) frequency

Table 4: Comparison between PI & Fuzzy Controller

s.no	Controller used	Delay time in sec	Rise time in sec	Settling time in sec	DC Link voltage under transient condition	AC voltage under fault condition	Transient behaviour
1.	PI controller	0.85	0.55	0.3	650	580	oscillatory
2.	Fuzzy controller	0.2	0.2	0.1	500	520	smooth

VI. CONCLUSION

Fuzzy Logic Control (FLC) design for wind- based HES is discussed and tried under various conditions. The results are shown effectiveness of the new control technique as compared with the traditional control technique. Comparing to PI controller, the Fuzzy Logic Control (FLC) fast response and can be manage the huge area of the operating conditions it is simpler and more flexible for controlling purpose. In proposed control scheme steady state errors and oscillations are reduced. the transients and frequency response will be improved. This control system provides better power quality and maintain stability. Therefore, the new control technique may be used for weak loads/grids like marine electric station by interchanging the wind systems to reduce the fossil fuel consumption.

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