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A Fuzzy Logic-Proportional Resonant Controller Based Coordinated Control Scheme for Standalone Wind Power System with Bess

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Abstract: ***The usage of Wind Energy Conversion Systems (WECS) in the standalone power systems that are increasing in the present scenario with the massive potential because of its high availability and low maintenance.Battery Energy Storage Systems (BESS) is applied to provide the voltage support in the standalone systems. Usually, Proportional Integral (PI) controller are applied for controlling the power in between the power generation and load. However, at thetime of unbalance load conditions, the performance of the PI controller is limited. In addition, with that, PI introduce steady-state errors and has restricted disturbance removalability. The conventional coordinated controllers also suffered from transient conditions at the time of dynamic load variations. To resolve these problems, this paper presents a Fuzzy logic based Proportional Resonant (PR) controller for providing better voltage support in the standalone wind power systems. As an alternative of the conventional PI controller, a PR controller is utilized in the coordinated control system. For optimizing the PR controller gain parameters, Fuzzy Logic Controller (FLC) is utilized. Performance of the proposed Fuzzy-PR controller is compared with the PI controller based coordinated controller. The outcomes demonstrate that the proposed controller delivers better DC voltage support compared with the general PI controller. Furthermore, the Total Harmonic Distortion (THD) of the presented system is very low contrasted with the standard control methods. MATLAB/SIMULINK tool is utilized to validate the system performance.***

Keywords : Coordinated control,Fuzzy logic Controller, Proportional Resonant controller,Wind power system

I. INTRODUCTION

The utilization of the Renewable-energy sources formanufacturing of electrical poweris needed to condense greenhouse gas emissions into the environment and to decreaseadverse variations in atmosphere [1]. In the renewable energy resources, the most important source is wind energy that is rapidincreasing technology [2].

The operation of a wind power-based power system is interesting task with the inconsistent environment of wind speed as well as variable load conditions, mostly while the method of operation of system powered with wind is independent [3]. Varying the wind speed sourcesvariations inturbine generator powered with wind, thatin the stand-alone wind-energy system causes variations in the load voltage and frequency [4]. Variable speed wind power systems produceextreme power and afford lower mechanical stress, greater power quality as well aseffectiveness than staticspeed of turbine systems powered with wind [5-6]. Whereas variable-speed wind systems, power-electronic systemsconsist of great prominence, which can be used to transmit generator side AC voltage to DC voltage thru variable frequency as well as constant magnitude at dc link [7]. DC-link voltage is changedto AC voltage through constant frequency andamplitude for power consumption at load [8].

Standalone wind-source power systems should compulsory consist of battery energizedloading systems forsourcingenergyas per requirement of load. The power produced at the WECS divergesas per wind speed fluctuations [9]. The BESS stores the poweronce the essential power load is slighter than the producedpower, and supply poweraccording to load necessitieswhilethe produced power is slighter than the essential load energybecause ofshort windspeeds [10]. Thedischarging&chargingphases of BESSregulatedthrough gating pulses given to dc-dc bi-directional buck/boost converter. The providing powerassists forupholding power-balance among the production, also load side controlsthat raise the consistency of power [11].

Permanent-Magnet Synchronous Generators (PMSG) were utilized forenhaning the consistency of stand-alone power systems thrufluctuation of speed inwind-energy production [12]. The inter-temporal variations and intermittency nature of the wind are the significant disadvantages in the WECS [13]. Due to this, the active power supplied by the wind generator, and it leads to the problem in the load balance. To regulate the output fluctuations, Energy Storage Systems (ESS) is used, i.e. batteries [14]. In standalone systems, the loads are installed based on the capacity of the wind systems. In these systems, when the power generation is high, the excess power is stored in the BESS.In some conditions, if the load is reduced, then the power generation from the wind should be reduced. Similarly, if an extra load is added, then BESS will provide the necessary power to the load [15].

Generally, coordinated control schemes are used for power management in the standalone WECS [16].

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However, the existing systems are cannot able to control the power effectively. The existing systems are failed to provide better DC voltage support in the BESS because many of the control schemes are involved Proportional Integral (PI) controller for the transformation process [17]. During the unbalance load situations, the PI controller performance is not satisfactory. In higher frequencies, the gain delivered by the PI controller is limited. The conventional coordinated controllers also suffered from transient conditions at the time of dynamic load variations. To rectify these issues, the present study develops Fuzzy logic based Proportional Resonant controller in lieu of providing better voltage support in the standalone wind power systems. Instead of the PI controller, a PR controller is utilized in coordinated control system. The gain constraints of the PR controller are optimized by using a fuzzy controller.

The structure of thisresearch is as mentioned: Section 2 deals with the related works, Section 3 defines the system components, Section 4explains the proposed coordinated control strategy, Section 5 illustrates the results and discussions followed by the conclusion and Future scope in Section 6.

II. RELATED WORKS

Shan et al. (2018) [18] proposed a predictive framework based on control approach of a micro-grid (MG)consisting solar-wind-battery resources. The authors have created theModel Predictive Current and Power (MPCP) arrangementforregulating bidirectional dc-dc converter in BESS, whereas,MPVPtechniquewas advancedfor regulating the ac/dclinking converter. Authors haveutilized to co-ordinatelyregulate the dc/dc converter; alsoac/dc converter forsleeking renewable energy outcomesfor sustainingdc-buses voltages.The authors have stated that, a comprehensive energy controlling plan has been advancedat the system level to safeguard sustainable operation under diverse operative methods. The efficiency of developed technique is centredover the solar-wind-battery system through real-time solar,as well as wind contourspresenting improved control efficiency compared to conventional schemes. It should be noted that the developedMPVP and MPCP methods require supplementarydimensionsrelated to customary cascade control including PID regulators. Therefore, surplus sensors as well as communication amenitieswereessential. Furthermore, the linking or delinking of filter capacitors in proceduremethod transformation triggered anexistingpoint in exercise. These issues have not been addressed in this work.

Kucuker et al. (2017) [19]developed adesign, control and switching centredfor energy controlling of Battery/PV / Windmicro-grid system. Developed micro-grid can be able to provide constant power flow consisting of greatconsistency. This developed one could also utilized with or without the synchronized / general grid throughdiversebasesfor attaining the most out of load energyfor the period of peak times. The dynamic performance of developedframework was examined for the logged weather outlines and load conditions. After the results of the Matlab simulation, outcomes havestated that created micro-grid meets entirecircumstances necessary towards energy quality and constancy of power system.

Wang et al. (2018) [20] proposed a decentralized harmonic compensation and reactive power managementtechniquehave beendevelopedon behalf of Voltage Control Mode and Current Control Mode in a Micro-Grid. Harmonic compensation was attained through employing virtual capacitive impedance and conductive induction, respectively, on behalf of the Current Control Mode andVoltage Control Modeelements. Available capacity of the proposed Virtual Admittance Inverter has been adapted to suit diversestandards of the reference energy of Current Control Mode units. Furthermore, the improved reactive as well as reverse droop regulatingpatternson behalf of the Voltage Control Modeand Current Control Mode elements respectively, have been proposed, taking into account their available capacity. Coordinate regulation of Current Control Mode and Voltage Control Modeelements was appliedfor employingthe local measurement; Therefore,central controllersas well as communication systems were not necessary. Experimental andsimulationoutcomes have shown theadoptingprocedures of Virtual Impedance as well as Admittance; compensation of CB voltage harmonics has been adequately attained. Moreover, the Current Control Mode and Voltage Control Modeelementsutilize the proposed reactive power compensation mechanism for contributing the reactive power compensation centred overtheenduringcapability of system. Therefore, structure is useful in applications like PV cells,whereas active power production is varyingall over the day.

Chang et al. (2018) [21] proposed a harmonizedregulated methodforHybrid ESS (HESS) for astandalone AC MG. Anabridged AC MG was presented, investigated andproposed of a simple active power allocation scheme. Under the proposed coordination regulatorapproach, the ultrasonic capacitor droop in the HESS is controlled and the AC MG is responsible for controlling the voltage andfrequency. As per the real-time frequency theory based on MG, active energyas well aspower of ultrasonic capacitor wasprojectedas well as replaced with lead-acid battery in HESS. In this presented control method, the auxiliary control competency of ultrasonic capacitor in HESS was considered and constant operation efficiency of HESS was enhanced. Furthermore, the understanding of proposed regulatorapproach was centred over local info and only required system frequencythat was actually suitable for application.

Motwani et al. (2018) [22] proposed the system, acombination of BESS, WECS and Solar were recognized. Maximum Power Point Tracking (MPPT) was employed to amplify the creation. The control system wasoperative as the battery was loadedonceextraenergy is accessible on generation side and unloadedonce extraenergyis attained thanproduced. The DC bus voltage was continuedendless for variable input conditions that resulted in steady and consistent output voltage in entire the cases regardless of the undesirable or temporary condition. However, the influences of load variations were not considered in this proposed work.

Hu et al. (2019) [23] presented a synchronizedregulatormethod of hybrid ac/dc micro-gridthrough Solar-wind-battery.The interfaced power converters at the local level were coordinated forregulating output current as well as voltage. The energy management system at the system level wasdevelopedforsustaining power balance in the adjustablepower generation as well as utility state. Numerous case studies on grid-linking in the standalone and grid synchronization phases has confirmed reasonable performance of micro-grid designas well as suggested regulation scheme.Associated to traditional cascade linear control, suggested scheme necessitateslower tuning work on converter control. However, the proposed system has showed that, the external voltage loop with PI regulators required for the stabilization of the DC-bus voltage.

Tummuru et al. (2019) [24] proposed a control scheme for grid interfaced and isolated hybrid energy systems. The voltage regulation and frequency at the common coupling point were attainedbelowisolated situations. Dynamic power at the time of transition over grid interfaced to isolatingas well as vice-versa was caughtwith supercapacitor pack. Therefore, the small signal average models of system were advancedfor investigating the constancybelowseveralworkingmethods.

Athira et al. (2017) [25] proposed regulating strategy for dc-dc converter switching centred over the load demand in isolated dc micro-grid that could stable the power as well asalso sustain dc bus voltage constant. Ultracapacitor besideby battery as a storage device was measuredfor enhancing the performance of battery. The relay was employed for controlling the pulsing of converters. System was tested belowchanging load conditions, as well asappropriatefunctioning of system comprising of PV panel as well as hybrid energy storage system was confirmed. Employing ultracapacitor, the lifespan of the battery be able toprolonged, and ithave afforded more energy through a smallperiod of time.

III. PROPOSED METHOD

A. Wind Energy Conversion System

The wind turbine power is expressed based on 3 parameters like air density, wind, swept surface [26].

$$\mathrm{P_V} = \frac{1}{2}\mathrm{r_0 S V^3} \quad (1)$$

Where,the air densityis denoted as $\mathrm{r_0}$, the wind speed is denoted as ‘V’, $\mathrm{S} = \mathrm{P}_i * \mathrm{R}^2$

Nevertheless, the wind energy of one part is changed as electrical energy that is presented in equation (2).

$$\mathrm{P}_{aer} = \mathrm{C_P P_V} \quad (2)$$

Where, $\mathrm{C_P}$ - the power coefficient.

$\mathrm{C_P}$ be influenced byover β (Beta) as well as λ (Lambda) denoting as pitch angle,tip speed ratio respectively which is presented as eq (3)

$$\lambda = \frac{\omega R}{V} \quad (3)$$

As a final point, the aerodynamic power is presented in eq (4)

$$\mathrm{P} = \frac{1}{2}\mathrm{r_0 P}_i\mathrm{R^2 C_P}(\lambda,\beta)\mathrm{V^3} \quad (4)$$

The equation of the mechanical torque is presented in eq (5)

$$\mathrm{P} = \frac{1}{2}\frac{\mathrm{r_0 P}_i\mathrm{R^2 C_P}(\lambda,\beta)\mathrm{V^3}}{W_\mathrm{P}} \quad (5)$$

The system is definedwithequation of electro-mechanical presented as

$$\mathrm{J}\frac{d\omega}{dt} = T_m - T_{em} - fw \quad (6)$$

Where, J - the inertia of the system,
f - friction.

B. Permanent magnet synchronous generator

Compared with the other generators in the WECS, PMSG has numerous advantages. Indeed, this PMSG is categorized by the great power density, greater efficiency, realisticvaluefor material. Furthermore, chain does not require forutilizing the gearbox. The machine wasaccountable for electrical energy translationthrough mechanical energy. The PMSG Electrical equations over the frame of alternated (d,q) waspresented in [27].

$$V_d = -R_s i_d - L_d \frac{di_q}{dt} + L_q i_q \omega_r \quad (7)$$

$$V_q = -R_s i_d - L_q \frac{di_q}{dt} - L_d i_d \omega_r + \phi_f \omega_r$$

(8)

Where, R_s isstator resistance,

ω is angular velocity and

ϕ_f is permanent magnetic flux.

Active and reactive power are functions of currentas well as voltage which is given in 9 and 10.

$$\mathrm{P}_S = \tfrac{3}{2}\left(V_d I_d + V_q I_q\right) \quad (9)$$

$$Q_S = \tfrac{3}{2}\left(V_d I_d - V_q I_q\right) \quad (10)$$

C. Battery Energy Storage System BESS

A battery is a device that can store energy in chemical elements and then convert it into electricity. The essential elements of every battery are categorized into three elements i.e., cathode and an anode these are two major terminals and an electrolyte. The electric charge flows through the electrolyte between cathode and anode. Therefore, while connecting a device to the battery, electrodes supply electrical power to the device. The Renewable Energy Sources (RES) power storage and the battery storage have the similar working principle. The operation of battery storage is the two tanks separated into the cathode and an anode, conferring to the movement of electrons through the stacks generates the voltage.

D. Proportional Resonant Controllers

For power converters, the output signals are dealt by controllers, thusly, design of the controller is a difficult task including the correct gain. Additionally,controllers should be reliable to harmonic disturbance rejection and control the performance at essential frequency. In zero frequency state of the PI controllers retaining a pole (with an unlimited gain), due to this fact in fundamental frequency state this controlleris not proficient of removing the steady-state error. Due to this drawback, instead of PI controllers, PR controllers are used. Both proportional term and resonant term combination are called as the PR controller. The equation of this controller is specified below [28].

$$C_{PR} = K_p + K_r \frac{s}{s^2+\omega^2} \qquad (11)$$

Where, ω - resonant frequency.

This type of controller consumes high gain in region of the resonant frequency, that is because of this characteristic, it can remove the steady-state error at the time of tracking or rejecting output signal [29], conferring to the principle of the internal model. The outcomes show that, PR controllers was extensively employed in inverter control. As per the case of improvinghandling harmonics performance with harmonic compensator presented as

$$C_{HC}(S) = \Sigma K_{rh} \frac{s}{s^2+(\omega h)^2} \qquad (12)$$

Where, h - harmonic order

It is appreciable, in that instance to sustain better controller performance, and the resonant frequency should remainsustained near to frequency of system. Whenfrequency of systemdiffersconsiderably, adaptive devicesbe able to adapted for adjusting resonant frequency conferring to frequency of system. When the PR controller employed in stationary reference (αβ) frame;where natural (abc) frame it is probablefor track the sinusoidal signal in order to eliminate the steady-state errors [30].

E. Fuzzy Logic Controller

Fig.1 illustrates the general diagram of the fuzzy logic system. In this fig.1, error as e, change in error as 'ce' and D – Duty cycle. The input error value and change of error are standardized by an input scaling factor. The input scaling factor of this system has been designed conferring to the input values among -1 and 1.

In the fuzzy logic controller the input variables aree as error,'ce' as Change of Error expressed below as [31],

$$e(k) = \frac{\Delta I}{\Delta V} + \frac{I}{V} = \frac{\Delta P}{\Delta V} = \frac{\Delta P}{\Delta I} \qquad (13)$$

$$ce(k) = e(k) - e(k-1) \qquad (14)$$

ΔI is $I(k) - I(k-1)$

ΔV is the $V(k) - V(k-1)$

As the above equation, the output current is referred as I, output voltages is referred as V from wind system [32].

- **Fuzzification**

The restraint inputs crisp values are changed into fuzzy values using the fuzzification module. The linguistic variables (fuzzy set or subset) are defined as fuzzy variables such as slow, big, medium, high, low, etc. A gradually varying membership function defines each fuzzy set. In fuzzy set expressions, every possible value, i.e., the variable can assume which are called the universe of discourse, and the fuzzy sets wrap the entire universe of discourse [32]. The fuzzy controller acts and process the input signal as per the rules specified into it and computes the appropriate restraint action (the fuzzy output variable) [33].

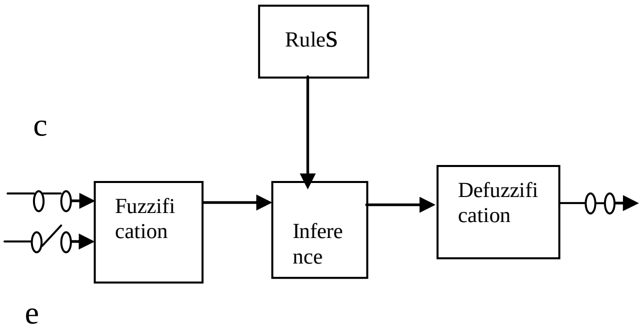


Figure.1 Generalized fuzzy logic system

- **Defuzzification**

The conversion of fuzzy values into crisp values by one of the mathematical procedures is named 'defuzzification'. A various method of defuzzification has been recommended that depends upon the application, and the available processing power the defuzzification method is chosen [34].

F. Fuzzy PR Controller

As per fundament frequency, traditional proportional integral controller wasrestricted gain resultantas static error overfollowing the sinusoidal AC signals. Instead at fundamental frequency, the PR controller has unlimited gain, thatbe able tounderstand the non-static error tracking restraint of output signal. Function of transfer of the PR controller presented as:

$$K_p(s) = K_p(s)^2 K_p + \frac{k}{\omega^2+s^2}$$

(15)

Where the proportional coefficient is Kp,

Though PR controller answers the issue of PI controller, which like wise devises certain limits over non-linear variation of the system because of fixed constraints. Taking this into account the above issues, it is essential for combing fuzzy restraint by PR restraint. The 2constraints of PR controllers wereaccustomed in real time conferring to error rate of wind system current and specified current. The systemwouldsort the controller furtherflexible to variations in System.

The fuzzy PR controller the whole thing as mentions. Initially, the preliminary values of parameters k_{p0} and k_{r0} in PR controllers are described to confer inverter's transfer function of restraint system. The varianceas well asvariation rate among reference as well as wind system current wereattained.

$$k_p = k_{p0} + \Delta k_p \qquad (16)$$

$$k_r = k_{r0} + \Delta k_r \qquad (17)$$

For the Fuzzy controller there are 2 factors as input. The fuzzy controller enhances output constraintsof PR controller based on fuzzy procedures.

Therefore, the fuzzy controller output for the PR controller changes afterwards the de-fuzzification. Then, the factorspreliminaryrateof PR controller is added to fuzzy controller outcomes. The valueswere definite restraint factors of PR controller. Fuzzy willunderstand real-time operationalalteration of PR factors,consequentlywhichschemedevisesdecentsteady-statea nd dynamic performance. Conferring to function factors of Kr,Kp of the controller, proposed system fuzzy procedures for K_p is expressed as revealed in table 1 and K_r formulated as shown in table 2.

Table 1: Fuzzy rules for K_p

e de	ng	nm	ns	z	ps	pm	Pg
	b	B	b	b	B	b	B
nm	s	B	b	b	B	b	S
ns	s	S	b	b	B	s	S
z	s	S	s	b	S	s	S
ps	s	S	b	b	B	s	s
pm	s	B	b	b	B	b	s
pb	b	B	b	b	B	b	b

The terms are negative small as ns, negative medium as nm, positive medium as pm, positive big as pb, big as b, small as s, zero as z, positive small as ps, negative great as ng.

It is referred from Table 1, if error is negative great and change in error is negative medium, then the resultant signal would be small. Then, the input signal in Table 2 results would be Big. Likewise, the resultant signals are obtained in the fuzzy controller. After calculating the fuzzy norm, the outcome is the fuzzy vector. As per the rule, this avoids ambiguity by using a weighted average evaluation. Fuzzy PR controller resolvesissue of static error developedwithprecise reference signal as well as prevents error of fixed parameter in PR controller.

To improve the performance of the standalone WECS, this approach proposes a fuzzy based proportional resonant controller. The block diagram of the proposed method is depicted in Fig. 2.

Table 2: Fuzzy rules for K_r

E De	ng	nm	ns	z	ps	pm	pg
ng	b	B	b	b	B	b	b
nm	b	B	b	b	B	b	s
ns	s	S	b	b	B	s	s
z	s	s	s	b	S	s	s
ps	s	s	b	b	B	s	s
pm	s	b	b	b	b	b	s
pb	b	b	b	b	b	b	b

As discussed, the traditional PI controller has the problem with the limited disturbance rejection quality and steady-state error. To rectify this problem Proportional-Resonant (PR), controller coordinated system is proposed. The PR controller will provide a steady state restraint of voltage and current in the standalone WECS. For providing better disturbance rejection and improved transient in a PR controller Fuzzy logic controller is applied. So, the proposed Fuzzy-PR controller will provide better restraint of power management in WECS. Once the power generation from WECS is higher than load power, then additional power will be stored in the BESS. If the battery is fully charged due to the use of MPPT, then derived from the reference current and reference voltage values the overcharging of the battery will be avoided. So, this proposed Fuzzy-PR controller will provide bettercoordinated restraint in the standalone WECS. The Block diagram for Fuzzy Logic PR coordinated Controller is shown in fig.3.

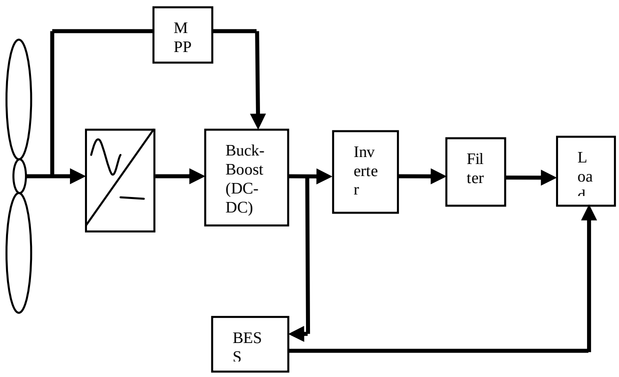


Figure 2. Block diagram of the proposed method

In this coordinated restraint strategy, the wind system explains the fuzzy-based proportional resonant controller operation. Initially, the V_{ref} and V_{dc} values are fetched into the comparator. The comparator output is sent into the fuzzy logic segment to get fuzzification and defuzzification results. Then the fuzzy output fed into PR controller here, andthe gain values of k_p and k_r values are obtained. These values are processed into the comparator with battery current. For getting a coordinated operation, the resultant value is multiplied by using the multiplier with lesser than or equal to function output which compares the SOC and constant. If the value is a predefined one, then the gate pulse is obtained and given into the converter.

The next segment gate pulse is for the Buck-Boost converter where, theV_{dc} and constant values are fetched into the comparator. The comparator result is fed into the fuzzy logic segment and the PR controller. The resultant is compared with less than or equal to function with the SOC and constant value comparison result. The resulting gate pulse is fed into the DC-DC converter. Therefore, based on the variation in the load, the pulses are generated and given to the converter for providing better voltage support.

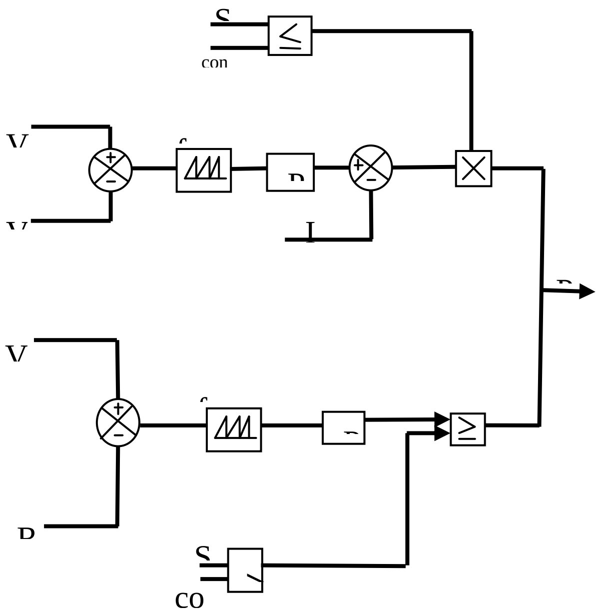


Figure 3. Block diagram for Fuzzy Logic PR coordinated Controller

IV. RESULT AND DISCUSSIONS

For evaluating the performance of the proposed methodology Fuzzy based PR controller is simulated as presented in fig.4. In this proposed system, initially, WECS is designed using PMSG.

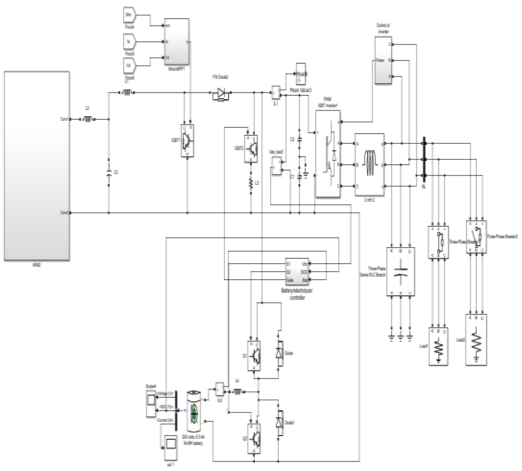


Fig. 4 Simulation Diagram of the proposed system

The power generated from PMSG is AC. By using the MPPT controller block, maximum power available in the WECS is extracted. Hence, by using a rectifier, it is converted into Dc. Then by using a Dc-Dc converter, the voltage is maintained constant. Then a battery is connected in between the converter and load. Then for supplying the AC loads a three-phase Voltage source inverter is connected with the DC-DC converter.The battery is connected to provide power whenever the load demand is varied. A three-phase inverter is connected with the system to supply the power to the AC loads. In this presented method, the LC filter is used for decreasing the harmonics in load side.Besides, the BESS is connected parallel with the system to store the excess power available in the system.

The fig.5 presents the illustration of wind power system simulation. By using the wind turbine, the torque is generated, and it is given as the input torque to the PMSG.

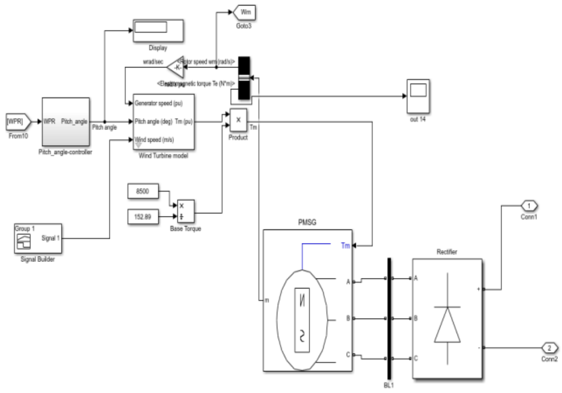


Fig.5 Simulation diagram of PMSG based wind power system

The performance of the proposed system is analyzed with variation in the wind speed. Fig.6 shows the simulation of variation in the wind speed. Here, the signal builder is used for giving the variable wind speed. Up to time t=4 sec, the wind speed is 12m/s and time t=4-6 sec the speed is reduced to 10m/s. After 6 sec, wind speed is changed again into 12m/s.

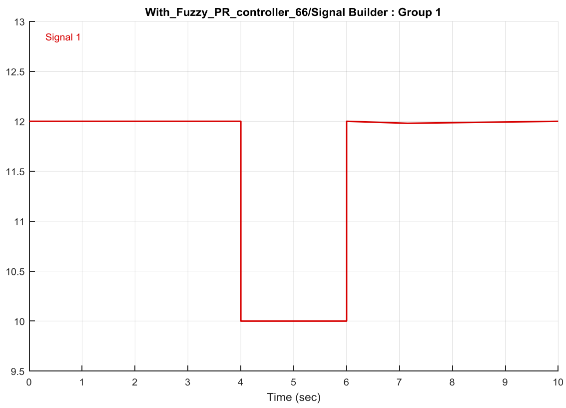


Fig.6 Speed variation in WECS

Fig.7 displays the fuzzy logic design of the proposed Fuzzy-PR coordinated controller. The values of Kp and Kr is selected by the fuzzy logic controller based on the membership functions shown in the below fig.8. Here,Mandani based fuzzy logic control is used.

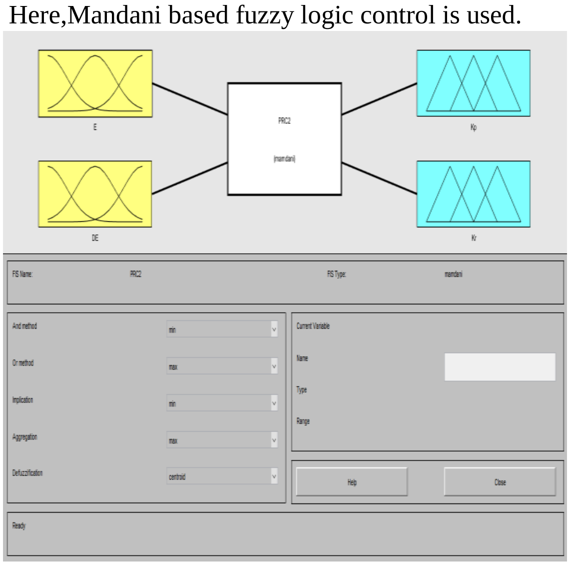
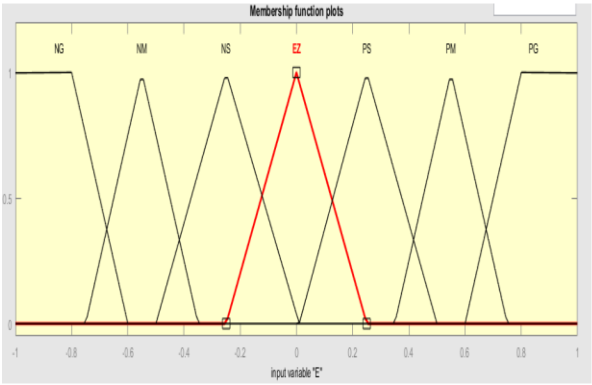


Fig 7. Fuzzy logic design of Proportional resonant controller



The fig.8 Fuzzy membership function of the proposed system

The control diagram of the proposed fuzzy-PR coordinated controller is illustrated in fig.9. The capacitor voltage at the inverter is compared with the reference dc voltage. The error and change in error are given to the fuzzy-based PR controller, and this signal is again compared with the battery SOC state. Based on this the gate signal for the DC-DC converter is generated.

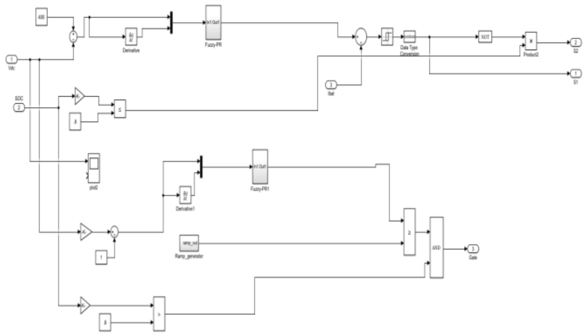


Figure 9. Simulation of the proposed system control strategy

The output voltage and current waveform at the load side are given in the below fig.10 and fig.11 respectively. It implies that the proposed coordinated controller provided sinusoidal output in the load side.

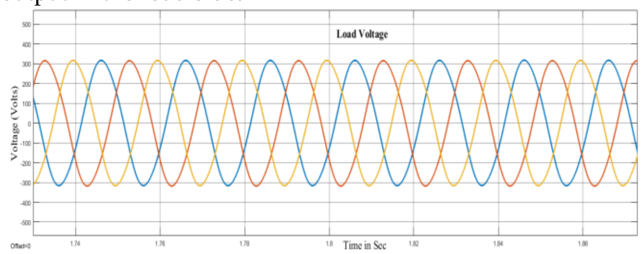


Figure 10. Load voltage

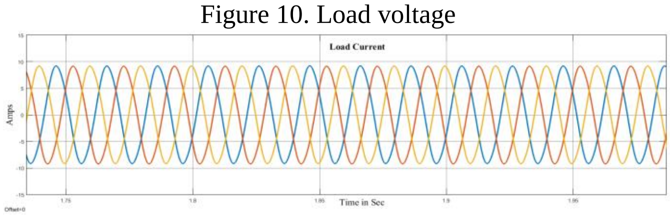


Figure.11 Load current

The output of the proposed coordinated control strategy in the standalone wind system is presented in fig.12. Initially, the system is operated at a constant load. Now, the power generated from the wind as constant. At time=1-2sec, the load is changed and to compensate this the power produced from the battery is also reduced.

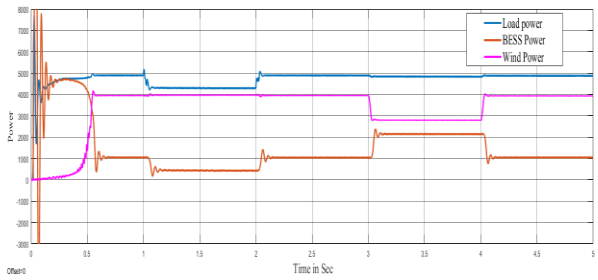


Figure 12. Power output of the proposed system

At time t=3 sec, the wind speed is reduced to 10m/s. Now, the power generated from the wind system is reduced. So, for providing the necessary power to the load, with the help of the coordinated controller, the power is supplied from battery to the load. At time t=4 sec, the wind speed is increased to 12m/s, now, the wind power is increased, and the power supplied from the battery is reduced.

Fig.13 and Fig.14 show the THD waveform of load voltage and load current controlled by the proposed fuzzy-PR coordinated controller.

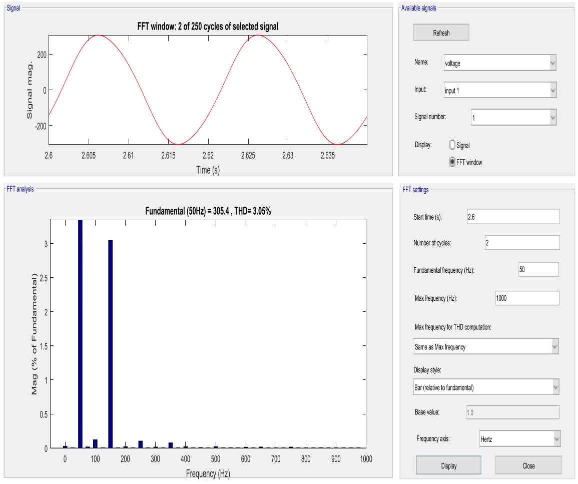


Fig.13 Voltage THD of the proposed system

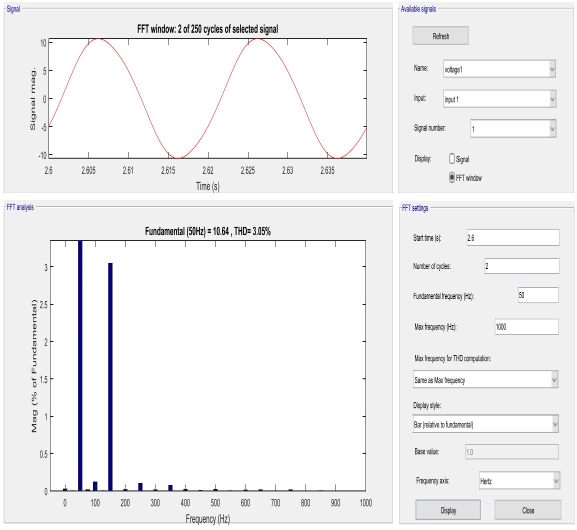


Fig. 14 Current THD of the proposed system

From the above results, it is shown that the proposed fuzzy-based Proportional Resonant controller effectively control the power in the standalone wind power system. The THD value of the output voltage is 3.05%, and output current is 3.05%. This is very low compared to the existing coordinated control methods.

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For validating the proposed system performance, the fuzzy-based PR controller performance is compared with the performance of the existing PI controller.

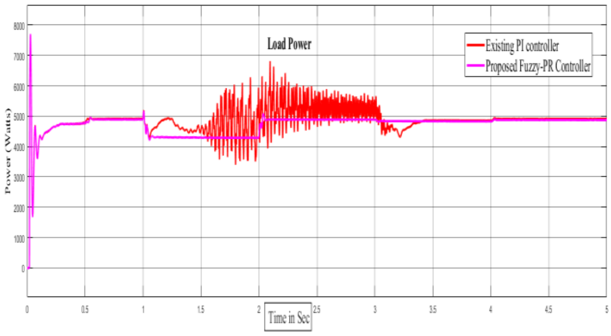

Fig. 15 Comparison of Load power

Fig.15 shows the comparison of the proposed coordinated controller with the existing controller in terms of load power. At time t=1 sec, the load is changed. The existing PI-based coordinated controller is failed to track this load variation, and it oscillates. However, the proposed fuzzy PR controller efficiently track the load variation and generate pulses accordingly.

Similarly, the proposed system is compared with the existing PI control based coordinated control strategy in terms of battery power, load power, and generator torque during the dynamics in load as well as wind power generation illustrated in fig.15, fig.16 and fig.17 respectively.

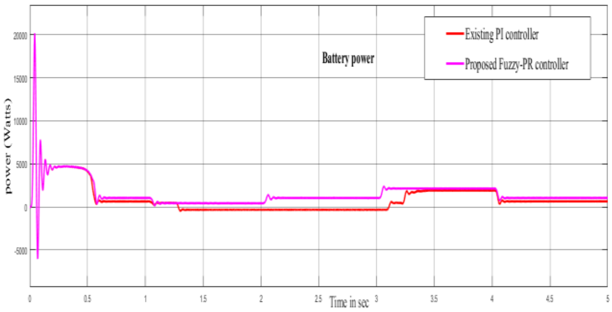

Fig. 16 Comparison of Battery power

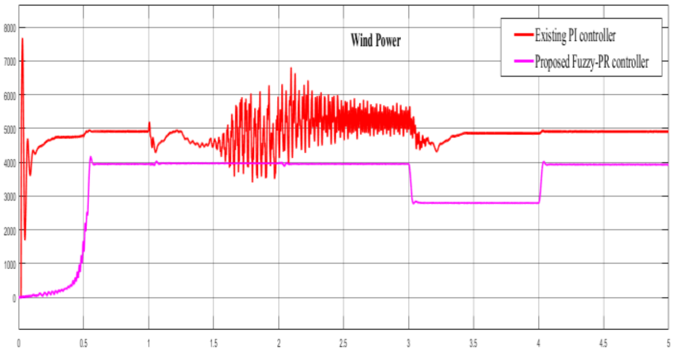

Fig. 17 Comparison of Wind power

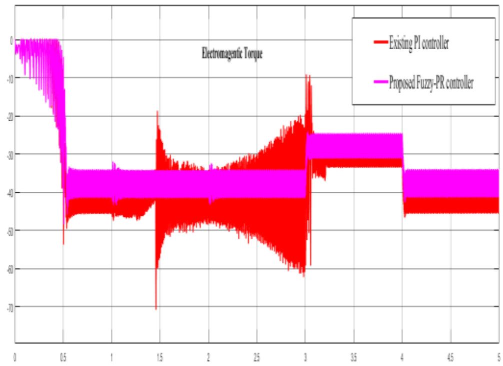

Fig. 17 Comparison of Generator Torque

Fig.18 shows the comparison of the battery voltage of proposed coordinated controller through existing PI-based coordinated controller. From this, proposed method is identified that proposed coordinated controller providesimprovedDC voltage support compared with the existing system during the variations in the load and power generation.

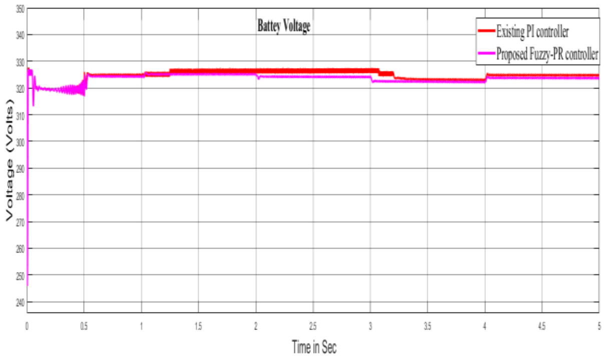

Fig. 18 Comparison of Battery Voltage

Table 3 THD comparison of the proposed system with the existing system

S.No	Voltage THD%	Current THD%
Existing PI controller	10.76	9.418
Fuzzy-PR controller(**Proposed**)	**3.05**	**3.05**

Table.3 explains the voltage and current performance of the proposed system with the existing system. The THD at the load voltage is 3.05% in the proposed fuzzy-PR controller whereas, it is 10.76% in the conventional PI control strategy. Similarly, the THD of the load current is 3.05% in the proposed fuzzy-PR controller, whereas it is 9.418% in the conventional PI control strategy. From the above results, it is shown that the proposed Fuzzy based PR controller has the better performance in terms of Power control, THD analysis, and DC voltage control.The proposed controller variation is very less compared with the conventional controller during the dynamic variation in the load and power generation. The THD at the load side also very less compared with the existing PI controller.

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V. CONCLUSION

This paper proposed a Fuzzy logic based Proportional Resonant controller for providing better voltage support in standalone wind power systems. Instead of conventional PI controller, a PR controller was employed in the coordinated control system. Fuzzy logic controller was applied for optimizing the PR controller gain parameters. The execution of proposed Fuzzy-PR coordinated controller was equated through conventional PI controller centered coordinated controller. The outcomes demonstrated that the proposed Fuzzy-PR controller provides better DC voltage support compared with the conventional controller. Furthermore, the THD of the presented system was very low compared with the conventional methods. MATLAB/SIMULINK tool was used to validate the system performance. In the future, the performance of the proposed system will be tested by grid-connected hybrid wind-solar system with addition of various linear and non-linear loads.

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