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Impacts Of Grounding Configurations On Responses Of Ground Protective Relays For Fuzzy Logic Controller Fed DFIG-Based Wind Generation

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Abstract—**Wind energy has picked up an expanding overall enthusiasm because of the nonstop increment in fuel cost and the need a perfect wellspring of energy. The fundamental target of the greater part of the wind energy frameworks is to extricate the most extreme power accessible in the wind stream. Be that as it may, the wind administration differs persistently and accordingly the framework controllers ought to be overhauled to take after these varieties. This paper is expected to apply fluffy rationale control systems to defeat the impact of the wind speed minor departure from the parameters of the wind turbines and their controllers. This paper researches effects of the grounding design on the execution of defensive gadgets used to shield DFIGs-based WECSs from electrical ground flaws. Examined grounding designs incorporate strong grounding, low-resistance grounding, high-resistance grounding, and no grounding. This paper likewise researches the utilization of a capacitor in parallel with a low resistance, as a grounding design, to farthest point ground possibilities, decrease ground streams, and minimize impacts on reactions of ground defensive transfers**

Keywords— Double Fed Induction Generator (DFIG), Fuzzy Logic Controller (FLC), Wind Energy, Grounding Faults

I. INTRODUCTION

Amid the previous couple of years, critical advance has been made to use different sorts of renewable energy sources. Among these renewable energy sources, wind energy has been driving the progressively developing levels of financial and practical electric energy generation. These developing levels of wind energy creation are bolstered by various advances that are focused by the doubly sustained acceptance generators (DFIGs). DFIG-based wind energy change systems (WECSs) can offer a few points of interest, including variable speed operation, controlled catching of wind power, decreased mechanical weights on the turbine and cutting edges, free control of dynamic and receptive powers, and somewhat evaluated power electronic converters (PECs) [1]–[8]. The expanding use of electric energy created by DFIG-based WECSs have ordered setting conditions for associating these disseminated producing units to power systems. Another arrangement of lattice codes has been built up to address the prerequisites for coordinating DFIG-based WECSs into power systems (see [9] for subtle elements).

One of the prerequisites of the new lattice codes is the compulsory interest of DFIG-based WECSs in voltage and recurrence control exercises of their host power systems [7]–[11]. For motivations behind agreeing to the new framework codes, a DFIG based WECS needs to stay associated with its host power systems amid relentless state and transient conditions. Such a necessity makes requests for precise and dependable insurance, and control of DFIG-based WECSs. A few episodes have been accounted for gear harm in the DFIG as well as its power electronic converters (see [7]–[9] and references in that) due to misidentified electrical ground flaws. Harm examinations for some of these episodes have demonstrated that shameful grounding arrangements have contributed altogether to the mal operation of ground defensive gadgets. As a result, the new matrix codes indicate introducing sufficient groundings for DFIG based WECSs. As a rule, grounding any segment in a power framework can be arranged as strong grounding, low-resistance grounding, high-resistance grounding, or no grounding [7]– [10]. The grounding of any producing unit (counting DFIG based WECSs) in a power framework ought to have the capacity to lessen ground currents and breaking point ground possibilities, which show up over the grounding impedance because of ground currents. It ought to be noticed that every wind turbine tower is outfitted with a different grounding that is in charge of a protected release of lightning strikes. This different grounding is built by an immediate association of the tower fortifications to ground anodes [7]–[14].

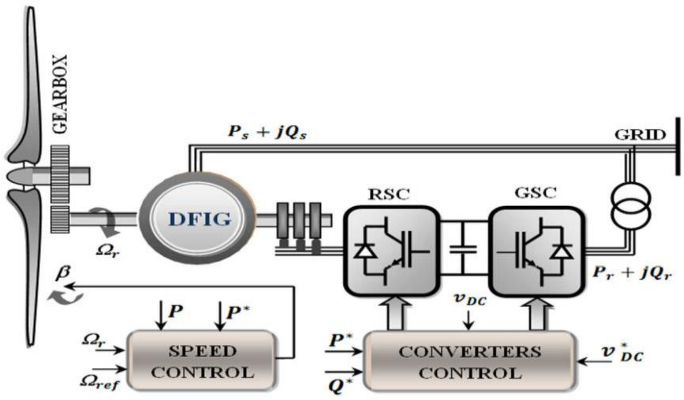


Fig. 1. Modular diagram of Studied system.

II. Topology And Principle Of Operation

A. Fuzzy Logic Controller

A fluffy rationale controller depends on an accumulation of control standards represented by the compositional lead of surmising connected to keep up the consistent voltage over the capacitor by minimizing the mistake between the capacitor voltage and it's reference voltage, the piece graph of a such control is delineated by the (Fig. 3).

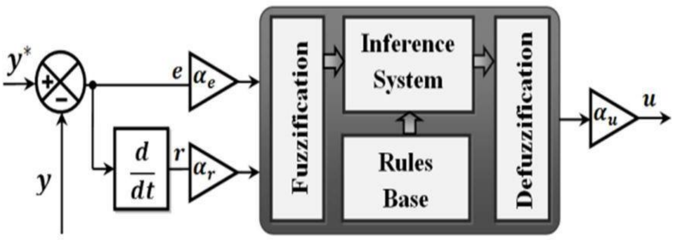


Fig. 2. Fuzzy controller structure.

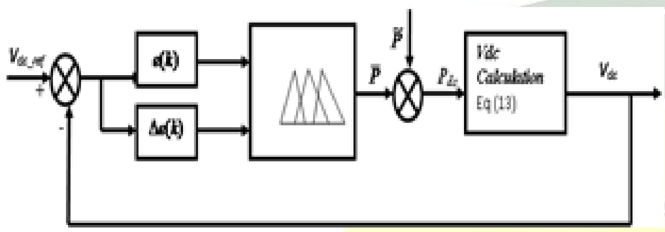


Fig. 3. Control of dc voltage source of SAPF.

A fluffy rationale controller (FLC) believers is propelled control technique (Mekri, 2007), (Hamadi, 2004) the based fluffy standards are developed by master experience or learning database. In the contribution of (FLC), the mistake e (k) and the Change of blunder Δe (k) have been put of the precise speed to be the info factors of the fluffy rationale controller. At that point the yield variable of (FLC) the fluffy rationale controller is displayed by the control voltage μ (k), the sort of fluffy surmising motor utilized is Mamdani. The phonetic information factors are characterized as (N, Z, P,) which, negative, zero, and positive individually. In The yield the semantic factors are characterized as (PB, PM, PS) which, positive huge, positive mean and, positive little zero separately. The fluffy standards are abridged in (Table I).

TABLE I. Rule base table

e(k) / $\otimes e(k)$					
N					
Z					
P					

The real power absorbed by DC voltage can be given by:

R_{dc}=d/dt(1/2 C_{dc}*V_{dc})^2……………………………………..1

For few variation value of DC voltage around its reference, we have:

Pdc=Cdc*Vdc ½ d/dt Vdc……………………………....2

After the use of Laplce transform

Vdc(s)=2Pdc(s)/Cdc*Vdc(s)……………………………3

The transfer function is defined

G(s)=2/Cdc*Vdc(s)……………………………………..4

The instantaneous error e(k) between v_{dc} and its e(k)=Vdc(k)ref-Vdc(k)………5

The change of the error can be calculated by

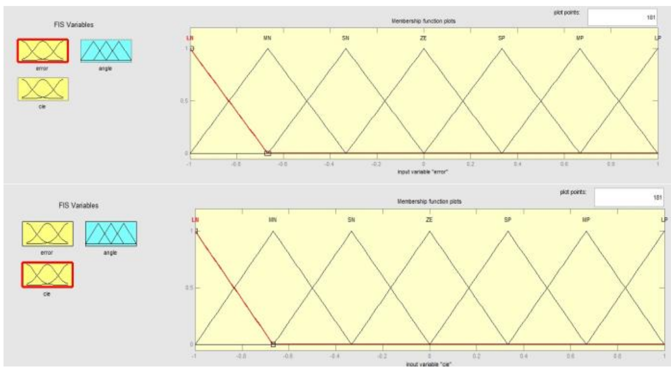
$$\otimes e(k) = e(k) - e(k\text{-}1)\ldots\ldots\ldots\ldots.6$$

The output of the fuzzy logic controller system is the change of the maximum current $\mu(k)$, the Product block outputs $P(k)$ is the result of multiplying of the error dc voltage $e(k)$ and the output maximum current of FLC obtained according to following equation:

$$P(k) = \mu(k) \cdot \otimes e(k)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.7$$

The membership functions of the fuzzy logic controller are shown in (Fig. 4. a, b,c).

1) Membership functions: The most elevated outing of the data sources is scaled to the information universe with a specific end goal to keep away from immersion. The signs estimating are gotten with modifying the FLC picks up. To build affectability, the information universe is part into seven triangular sets crossing their bordering at the medium participation esteem as delineated in Fig.3. This gives an adequate affectability for the situation consider. The yield sets are diminished to singleton to rearrange the Center Of Gravity COG deffuzification calculation. Each little range of the FLC exchange guide can be effectively balanced with basically adjusting the relating rules which permits a neighborhood tweaking of the reaction for every estimation of the data sources. This gives FLC a delicate setup prompting a powerful adaptability.



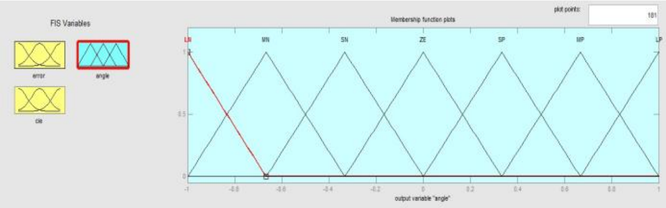


Fig. 4. Membership functions of the fuzzy logic controller are shown in (Fig. 4. a, b,c).

2) Fuzzy regulator tuning: For FLC basic outlining, it is part into decoupled corresponding and vital fluffy controllers. The hand-tuning first stage follows up on the Fuzzy Proportional controller picks up. The calibrating is gotten in the second stage by modifying the basic pick up to expel any last esteem balance. The relating chart is portrayed in Fig.4.

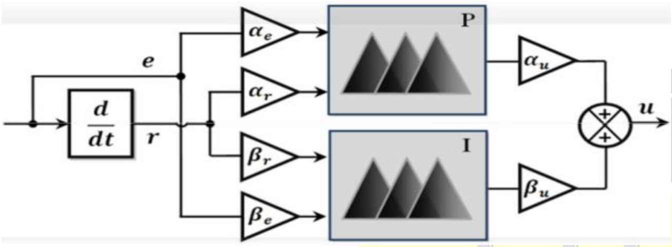


Fig. 5. Proportional and Integral Fuzzy controller.

III. Grounding Configurations In DFIG-Based WECSs

A. Overview of Grounding Configurations

Diverse grounding designs permit the restriction of ground blame currents, and additionally the diminishment of ground potentials experienced by different segments in any power framework. This gets to be basic while considering the part of grounding in the strength, unwavering quality, and operation of DFIG-based WECSs due to [6]–[11]. The livelihood of PECs in rotors of DFIGs. These PECs create current symphonious segments that stream to the ground, and may disturb the capacity of any ground defensive gadget. The utilization of links to associate the DFIG (situated at the highest point of the wind turbine tower) to the gathering transformer. The noteworthy equal capacitances of these links can start transient over voltages amid topsy-turvy electrical flaws. Such transient over voltages may prompt ensuing disappointments in DFIG-based WECSs.

Institutionalized practices for grounding power systems components recognize four essential setups [19]–[20].

1) Solid Grounding: This grounding arrangement is established by wiping out any purposeful impedance between the nonpartisan and ground focuses. The primary preferred standpoint of the strong grounding is its capacity to dispose of ground possibilities. Be that as it may, this grounding design does not offer any diminishment of ground currents. Such a dis-advantage raises worries about its applications in DFIG-based WECSs, where ground blames in the rotor PECs can start higher currents than those started by 3φ blames, and may bring about extreme hardware harm.

2) Low-Resistance Grounding: Mechanical practices consider a low-resistance grounding as a resistance associate ing the impartial and ground focuses, and is equipped for keeping up the ground current IG as.

- IG ≤ 100 A: low-voltage (Vsys ≤ 1 kV);
- IG ≤ 400 A: medium voltage (1 < Vsys ≤ 35 kV).

It is to be noticed that low and medium voltages are considered since they speak to run of the mill appraised voltages of DFIG-based WECSs. The low-resistance grounding setup offers a few points of interest, including decreased arcing currents and constrained circular segment streak dangers prompting ground flaws, diminished mechanical and warm harms in the transformer as well as DFIG, and lessened ground possibilities. Be that as it may, this grounding design does not bolster blame area highlights.

3) High-Resistance Grounding: This grounding configuration is characterized as a resistance interfacing the unbiased and ground focuses, and is equipped for lessening ground currents to under 25 An (in low and medium voltage systems). The high-resistance grounding offers a few preferences that incorporate encouraging the way toward finding deficiencies and minimizing the utilization of the ground. In any case, this grounding setup may entangle the elements of ground defensive gadgets because of the critical decreases of ground currents, alongside high ground possibilities.

4) No Grounding: The no-grounding setup is established by an open circuit between the nonpartisan and ground focuses. Amid any ground blame, the no-grounding configuration permits the line-to-nonpartisan voltage VP to change with the end goal that for broken phase(s) VP = 0, and for sound phase(s) VP = VL; where VL is the framework line-to-line voltage. The change in VP may upset the reactions of defensive gadgets, and in addition the operation of rotor PECs [16]–[21].

B. Grounding DFIG-Based WECSs

Fig. 1 demonstrates a routine schematic for a DFIG-based WECS, alongside its grounding area. The rotor windings of an acceptance generator that is utilized as a part of a DFIG-based WECS, are specifically associated with the rotor-side 3φ PEC. The rotor-side PEC can be worked as a 3φ ac–dc PEC, 3φ dc–ac PEC, or bidirectional 3φ PEC. Moreover, the rotor-side PEC is connected by means of a dc interface capacitor to the network side PEC, which can be worked as a 3φ ac–dc PEC, 3φ dc–ac PEC, or bidirectional 3φ PEC. The exchanging activities of the rotor-side PEC create progressive voltage driving forces with critical extents. Such voltage driving forces make overvoltage focuses between individual rotor windings and the ground, and can curve harms on the rotor circuit under states of high ground possibilities [7], [8], [19]. As a result, additional weight is put on the sufficiency of the grounding design for a DFIG-based WECS.

To stay away from harms brought on by overvoltage pushes in the rotor windings, ground possibilities must be kept at low values. A low-resistance-grounding arrangement can be utilized because of its capacity to cutoff ground possibilities, which may get to be noteworthy as an aftereffect of current consonant segments created by the rotor PECs. In such manner, high ground possibilities may bring about [22]–[25]

- Nuisance operation of ground defensive gadgets;
- Inaccurate detail of grounding resistances;
- Amplified voltage focuses over the rotor 3φ windings.

The previously mentioned concerns propose that a low-resistance grounding can restrain ground possibilities actuated by current harmonic segments delivered by the rotor PECs [23]–[25].

Most by far of electrical issues experienced by power framework parts, including DFIG-based WECSs, are ground issues. A ground blame is instated by an accidental association somewhere around one and a greater amount of the stimulated stages to the ground point. Among the regular reasons for ground flaws are protection breakdown, inappropriate associations, broken transport bars, and disappointment of framework component(s). Distinctive power framework segments are by and large secured against ground blames by utilizing ground defensive gadgets. Ground defensive gadgets are utilized to recognize either the current streaming to the ground as well as voltage (usually called the ground potential) crosswise over grounding resistances or impedances. On account of ground current or potential surpassing the get esteem and time setting, ground defensive gadgets start their reaction [trip at least one circuit breakers (CBs)] [21]–[25]. There are a few outlines of ground defensive gadgets including overcur-lease (converse, reverse distinct, and so on.) and advanced (consonant based, design acknowledgment, and so on.) transfers.

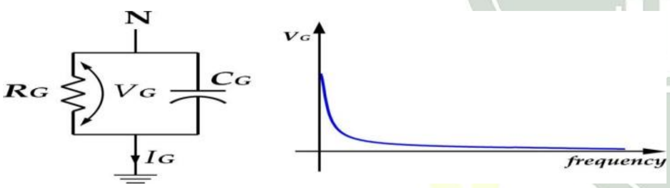


Fig. 6. Frequency selective circuit for the low-resistance grounding of a DFIG-based WECS and its ground potential *VG* characteristics.

The occupation of PECs in the rotor of a DFIG causes current symphonious segments to stream to the ground. On the off chance that a low-resistance grounding, with a resistance RG, is utilized for a DFIG-based WECS, the current consonant segments streaming to the component. This recurrence determination highlight can be acknowledged by incorporating a capacitance CG in parallel with the low-resistance grounding RG, as appeared in Fig. 6 [23]. The changed circuit for the low-resistance grounding will piece high-recurrence currents from coursing through RG, as CG offers a low-impedance way for these currents. This plan of the low-resistance grounding will work as a channel that lessens high recurrence ground possibilities crosswise over RG [23]. For plan purposes, the overwhelming consonant part in the ground current IG is thought to be the third symphonious. Keeping in mind the end goal to choose CG, the estimation of RG is set to be five times higher than the impedance of CG. This can be communicated as ground will make a ground potential crosswise over RG.

Rg=5/2π*3*fs*Cg

Where *fs* is the system frequency.

IV. Double Fed Induction Generator

DFIG is a shortening for Double Fed Induction Generator, a creating rule generally utilized as a part of wind turbines. It depends on an enlistment generator with a multiphase injury rotor and a multiphase slip ring get together with brushes for access to the rotor windings. It is conceivable to keep away from the multiphase slip ring gathering (see brushless doubly-encouraged electric machines), yet there are issues with productivity, cost and size. A superior option is a brushless injury rotor doubly-sustained electric machine.

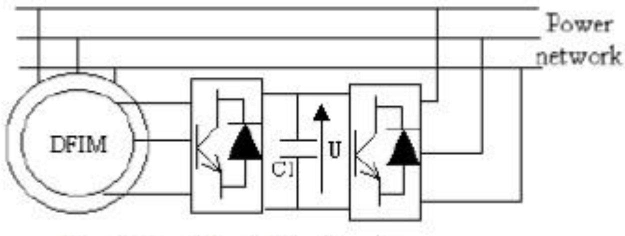


Fig. 7. DFIG Line Circuit.

V. Simulation Results

A few reproduction tests were done to examine effects of grounding designs on the reactions of ground defensive transfers utilized as a part of DFIG-based WECSs. Two DFIG-based WECSs were utilized as a part of these reenactment tests; one was appraised at 15 kW, and the other was evaluated at 2 kW. The model and test comes about for 15-kW DFIG-based WECSs are introduced here, and the model of the 2-kW DFIG-based WECS, alongside its test outcomes, are given in Appendix I.

A. Modeling the 15-kW DFIG-Based WECS

For reasons for researching conceivable effects of the ground-ing setups, including the changed low-resistance grounding (as appeared in Fig. 2), a DFIG-based WECS was actualized utilizing a MATLAB/SIMULINK display, where the DFIG was developed utilizing the point by point show [26]. The determinations of the acceptance generator, rotor PECs, and principle transformer in the executed model are given in Table I. The executed SIMULINK show used two vector controllers for creating reference signals, which were utilized for delivering beat width balanced (PWM) switch-ing beats for the rotor PECs. These vector controllers were outlined as nitty gritty in [8], and with PWM exchanging signs were created at an exchanging recurrence of 8 kHz. Reenactment tests were performed with a period venture of Ts = 50 μs. The tests for exploring effects of grounding setups were directed on two diverse defensive gadgets.

- An inverse definite minimum time overcurrent (IDMTOC) relay, with 20 A pick-up current and 0.3-s time dial [27].
- A discrete Fourier transform (DFT)-based digital relay.

The ground current IG was utilized as the contribution for both defensive transfers. The information in Table I was utilized for determining values for the resistances utilized as a part of low-and high-resistance grounding setups. These resistance qualities were determined as:

1) Low resistance: The maximum ground current was set 30 A, which was selected to meet standards for ground currents in low-voltage systems ($I_G \leq 100$ A). Equation (1) was used to calculate $(R_G)_{LRG}$ for $V_P = (430/\sqrt{3})$ and $I_G = 30$ A. The ohmic value of $(R_G)_{LRG}$ was calculated as $(R_G)_{LRG} = 8.275\ \Omega$. The power rating for $(R_G)_{LRG}$ was specified using (2), for $I_G = 30$ A, as $(P_R)_{LRG} = 7.45$kW.

The IEC 60255 standard specifies the characteristics of IDMTOC relays as: Tres=(C*TMS)/I*α*Id

T_{res}: response time, $C = 0.14$, Id: current set point, I: relay input current, $\alpha = 0.02$ for inverse-time overcurrent relay, and $TMS = 0.5$: time multiplier setting for tripping time [27].

2) High resistance: The maximum ground current was set 8 A to meet the standards for the ground current in high-resistance grounding ($I_G \leq 25$ A). The ohmic value of $(R_G)_{HRG}$ was determined using (1) for $V_P = (430/\sqrt{3})$ V and $I_G = 8$ A, and was found as $(R_G)_{HRG} = 31.033\ \Omega$. The power rating for $(R_G)_{HRG}$ was specified using (2), for $I_G = 8$ A, as $(P_R)_{HRG} = 2.5$kW.

The capacitance C_G, used to modify the low-resistance grounding was determined as $C_G = 535\ \mu$F (using (3)). Moreover, the voltage rating of C_G was selected as the nominal line-to-line voltage of the DFIG-based WECS. The specified values for $(R_G)_{LRG}$, $(R_G)_{HRG}$, and C_G were used in simulation tests.

B. *Simulation Results for the 15-kW DFIG-Based WECS*

The SIMULINK model of the 15-kW DFIG-based WECS was tested for several fault and nonfault conditions to investigate possible impacts of each grounding configuration on the responses of ground protective devices.

Case 1—Nonfault Conditions: In this test, the DFIG-based WECS was worked to convey its evaluated power for a variable wind speed vw that was started at 8 m/s, diminished to 7.5 m/s at t = 2.5 s, expanded to 8.5 m/s at t = 3.5 s, and expanded to 10 m/s at t = 4.2 s. A sudden lessening of 15% in the terminal voltage of the DFIG-based WECS was made amid t = 2.5–4 s. This voltage decrease was made to imitate a low-voltage ride-through (LVRT) condition. It ought to be noticed that the reaction of every transfer (the trek flag) was introduced at a high state (TRIP = 1), which was changed to a low state (TRIP = 0) in the event of a distinguished blame. The ground potential, ground current, and outing signals created by the IDMTOC and DFT transfers for the fundamental grounding designs are appeared in Fig. 3.

Reenactment brings about Fig. 3 demonstrate that every grounding con figuration influenced the ground potential VG and current IG in various degrees. The strong grounding brought about VG =0 and (IG)peak = 1.24 A. In addition, the low-resistance grounding restricted VG to (VG)peak = 6.72 V and delivered (IG)peak = 0.81 A. The high-resistance grounding yielded (IG)peak = 0.37 An and (VG)peak = 14.48 V. At last, the no grounding re-sulted in IG =0 and (VG)peak = 40.47 V. The outcomes in Fig. 3 showed that the low-resistance grounding design created adequate qualities for VG and IG. Similar non-fault test was led keeping in mind the end goal to test the execution of the changed low-resistance grounding (RG in parallel with CG). The ground potential, ground current, and trek signs of both transfers, for the nonfault condition, are appeared in Fig. 4. One can see from Fig. 4 that the ground potential VG demonstrated a further diminishment than that acquired by utilizing the routine low-resistance grounding. This decrease in VG was proficient because of the consideration of CG, which gave a low impedance way to the current symphonious parts, and brought on an expansion in the ground current contrasted and the low-resistance grounding.

Case 2—Phase A-to-Ground Fault: This test was led as the DFIG-based WECS was set to convey half of its appraised power at an altered twist speed of vw = 8.5 m/s. At t =3 s, stage An, on the yield of the rotor 3φ dc–ac converter, was associated with the ground to make a line-to-ground blame. Fig. 5 demonstrates the ground potential, ground current, and outing signs of the tried transfers for essential grounding arrangements.

The reenactment brings about Fig. 5 for the stage A-to-ground blame in the rotor demonstrate that every grounding setup affected the reactions of both transfers. This was seen as the trek signs of the IDMTOC and DFT transfers were created at an alternate time for every grounding arrangement. The strong grounding setup permitted IG to achieve a pinnacle estimation of 136.4 A. The low-resistance grounding diminished IG to have a pinnacle estimation of 41.5 A, while the high-resistance grounding diminished the pinnacle estimation of IG to 10.7 A. No grounding brought about a ground blame current of 0 A. A rundown for the recreation results is given in Table II. For reasons for examining the effects of the adjusted low-resistance grounding, similar test was directed, and the outcomes are appeared in Fig. 6. It is appeared from Fig. 6 that the ground current was de-wrinkled when the DFIG was grounded utilizing the changed low-resistance grounding. The high ground current amid the blame conditions encouraged the era of both outing signals in shorter times than those saw in Fig. 5(b). The recurrence choice component of the changed low-resistance grounding al-lowed both transfers to recognize the ground blame and produce their trek motions in under 4 cycles after the blame began. Other ground blames in the rotor and stator of the DFIG were tried, and their outcomes are abridged in Table II. The information in Table II demonstrates that every grounding configuration affected the reactions of defensive gadgets for various ground deficiencies. Moreover, Table II demonstrates that the changed low-resistance grounding (RG in parallel with CG) offered restricting ground possibilities and diminishing ground currents (contrasted and those created by strong grounding). Accordingly, trip signs of the IDMTOC and DFT transfers were produced speedier than those created when ground possibilities had nonzero values. In outline, the reproduction results and information in Table II give support to the execution of the changed low-resistance grounding setup for DFIG-based WECSs to encourage appropriate reactions of ground defensive transfers.

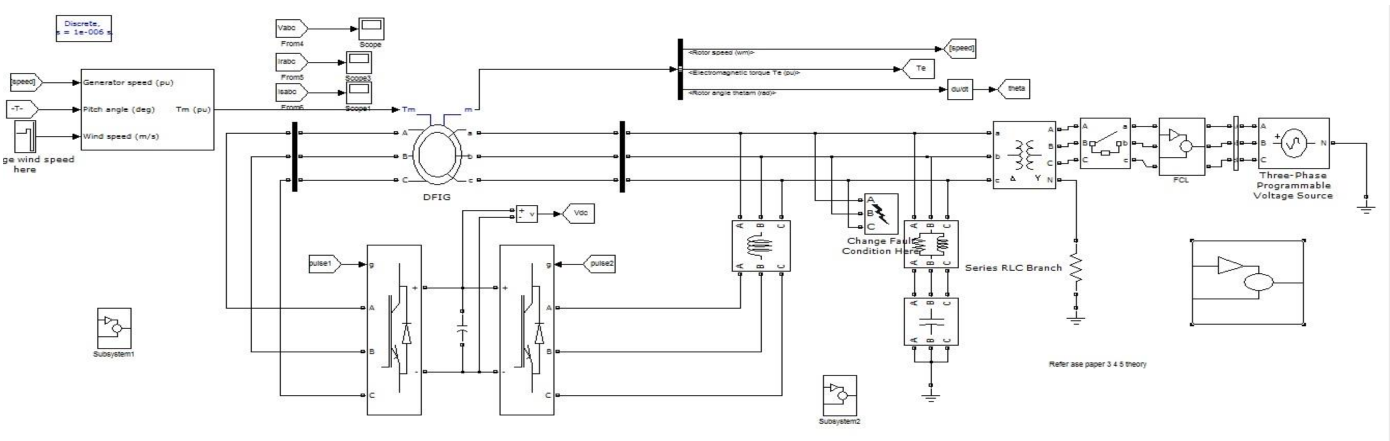


Fig. 8. Simulation of FLC-DFIG.

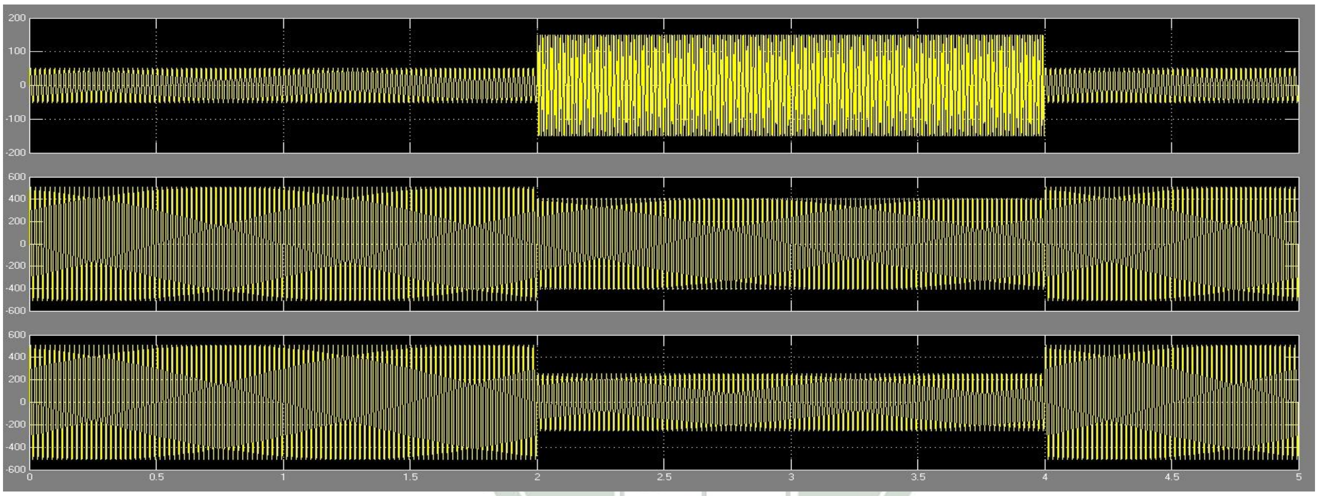


Fig. 9. Impacts of grounding configurations on ground protective devices used in PI controlled - DFIG-based WECS for phase *A*,*B*,*C*-to-ground fault on the output of the rotor dc–ac converter. The ground potential V_G, ground current I_G, and trip signals.

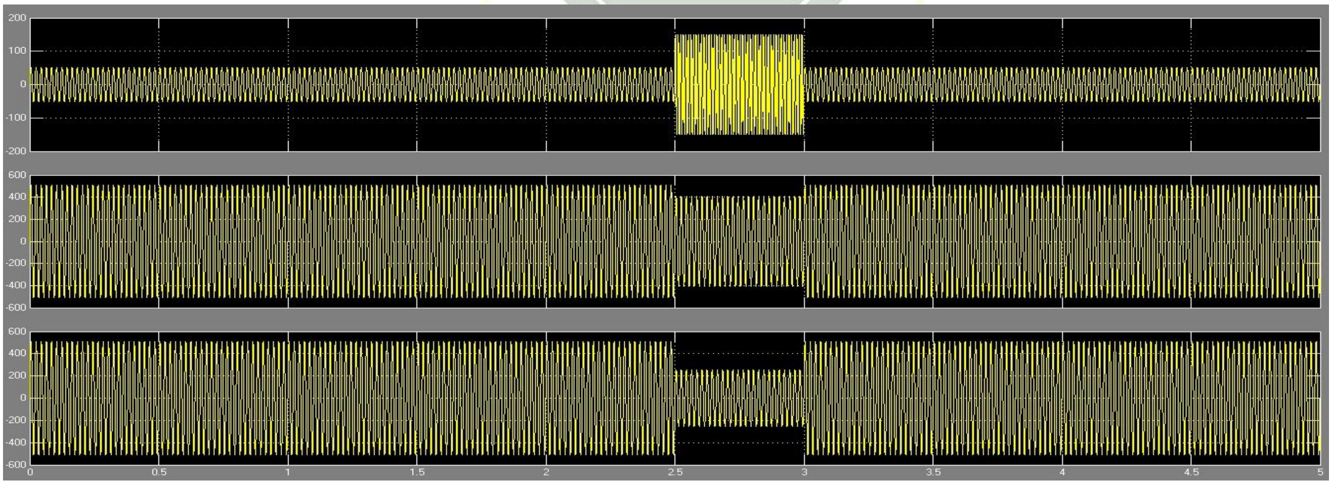


Fig. 10. Impacts of grounding configurations on ground protective devices used in Fuzzy Lgic controlled - DFIG-based WECS for phase *A*,*B*,*C*-to-ground fault on the output of the rotor dc–ac converter. The ground potential V_G, ground current I_G, and trip signals.

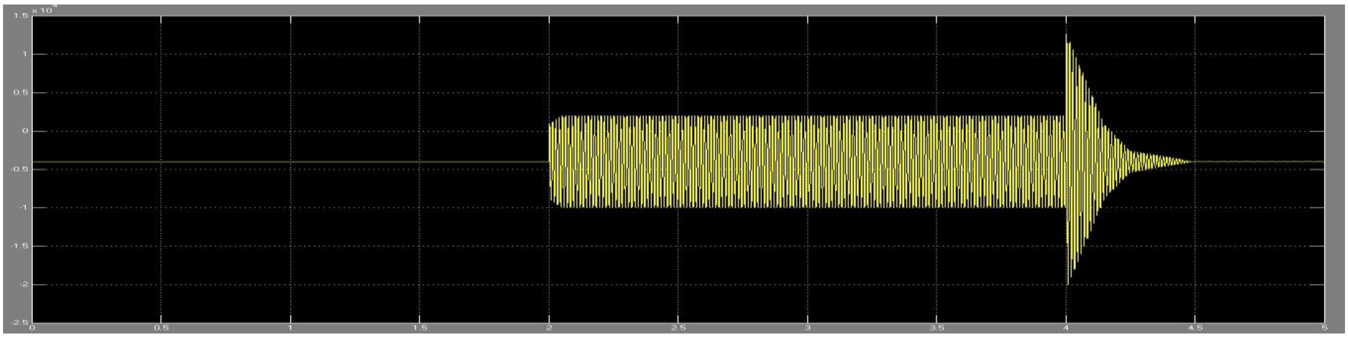


Fig. 11. Impacts of grounding configurations on ground protective devices for phase *A,B,C*-to-ground fault.

CONCLUSION

This paper has examined the effects of different grounding arrangements, including strong, low resistance, high resistance, and no grounding, on the usefulness and execution of ground defensive gadgets utilized as a part of DFIG-based WECSs. Examined impacts have incorporated the capacity of defensive gadgets to distinguish ground flaws, alongside the time required to react to a recognized blame. Test comes about have exhibited that every grounding setup changes ground possibilities and currents. On one hand, basic requirements for diminishing ground possibilities emerge from the way that enduring state current consonant segments stream to the ground, where substantial ground possibilities may confound the operation of the rotor PECs. Then again, low ground currents, as on account of high-resistance grounding, may bring about mal-operations of ground defensive gadgets, which utilize ground currents to recognize shortcomings. A Fuzzy Logic Controller has been tried for applications in grounding DFIG-based WECSs. This grounding design has been discovered ready to point of confinement ground possibilities and decrease ground currents, while forcing minor effects on reactions of ground defensive transfers. Recreation tests have been directed to build up top to bottom perceptions under states of various wind speeds and levels of power era. Comes about because of these tests bolster the utilization of the changed low-resistance grounding to guarantee minimized effects on the ground defensive gadgets utilized for DFIG-based WECSs.

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