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OPEN-CIRCUIT FAULT-TOLERANT CONTROL FOR OUTER SWITCHES OF FIVE- LEVEL RECTIFIERS IN WIND TURBINE SYSTEMS

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***Abstract*— A five - level converter which is used as the power converters for wind turbine systems on account of their merits, for example, high effectiveness, low-current total harmonic distortion, and furthermore low collector– emitter voltage. Interior perpetual magnet synchronous generators (IPMSGs) is actualized as the generator in the wind turbine systems which is inferable from their merits of effectiveness and size along these lines in the wind turbine systems may substance of the five-level converter and the IPMSG, fault-tolerant controls for an open-circuit fault of switches have been set up and it is utilized to enhance unwavering quality. In this paper which is centers around the open-circuit fault with the external switches (Sx1andSx4) in five level rectifiers (both impartial point cinched and T-type) which are associated with the IPMSG. And further more what's, the impacts of Sx1 and Sx4 open-circuit faults which are dissected, and it is rely on there examination, a tolerant control is proposed. The proposed tolerant control is maintains with the ordinary operation for the sinusoidal currents under the open-circuit fault with external switches by the expansion with the remuneration incentive to the reference voltages.**

***Keywords:* - Five - level converter, wind turbine systems, Interior perpetual magnet synchronous generators (IPMSGs), Fault-tolerant controls, impartial point cinched, T-type, open-circuit fault.**

I. INTRODUCTION

The power capacity of a turbine system has been expanding systematically, bringing about the occasion of generators with goliath power ability [1]– [3]. There are numerous sorts of generators magnet synchronous generators (PMSGs) have high strength and high responsibleness contrasted and enlistment generators. This can be because of outer excitation isn't required and there aren't any copper losses inside the rotor circuits. Also, attributable to the littler size of the PMSG, the load of the turbine is lessened [4].

Among various PMSGs, interior PMSGs (IPMSGs) are especially profitable from the standpoints of strength and power generation on account of the usage of the hesitance compel [4]–[7]. Generators requiring high voltage must be constrained to utilize structure convertor topologies to reduce the collector– emitter voltage per switch. Among structure topologies, three-level topologies like the three-level unbiased point clasped (5L-NPC) and T-type topologies are connected in turbine systems with a decent power change. The five - level topology will basically be extended from a two-level topology and is moreover less demanding to manage contrasted and diverse structure topologies.

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Along these lines, the five - level topology ensures high power and low-current total harmonic distortion (THD) as contrasted and the two level topology [8]– [11]. The 5L-NPC topology is at risk to switch faults because of a few switches are utilized. Switch fault identification and tolerant administration courses for change faults should be authorized to improve the responsibleness of turbine systems. Switch faults are isolated into a short out fault and an open-circuit fault [12]. The short out fault normally winds up in a breakdown of the entire system; thus, fault discovery and tolerant administration routes for the short out fault require additionally circuits. On the contrary hand, the open-circuit fault winds up in current distortion, which may bring about a breakdown in the event that it endures for a broadened time; thus, the open-circuit fault should be distinguished, and along these lines the tolerant controls are fundamental [9], [12]– [15]. In turbine systems, a succeeding convertor is utilized to exchange power from the generator to the grid. A back-to back convertor misuses the 5L-NPC topology is appeared in Fig. 1.

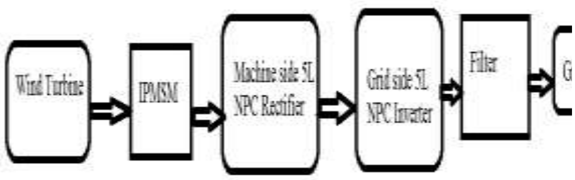

Fig. 1. Back-to-back converter using the 5L-NPC topology in wind turbine systems.

This comprises of the machine-side 5L-NPC rectifier, the dc-link, and furthermore the grid-side 5L-NPC electrical converter depending on the operational conditions, tolerant controls is connected for the rectifier or the electrical converter because of this methods for the rectifier and furthermore the electrical converter zone unit totally unique [9], [13]– [15]. also, the different structure of the five - level topologies should be pondered inside the tolerant controls [9], [13]. inside the 5L-NPC electrical converter, the open-circuit fault of the inward switch causes the external change associated it to be infeasible; in this way, regularly changing exclusively the move method doesn't turn into a response for the open-circuit fault, and furthermore the further devices like wires and switches should be extra to achieve the tolerant operation underneath the open-circuit fault of the internal switch [16]–[18].

Be that as it may, the open-circuit fault of the external switch is dealt with by altered the move strategy in limited differ [19]. In [19], the tolerant administration procedure restricts the output voltage differ by 0.5 inside the 5L-NPC rectifier, this distortion caused by the open-circuit fault of the internal switch is restored part by cinching the move state with none further devices [14]. moreover the reactive current is infused to kill current distortion caused by the open-circuit fault of the external switch [22]. This method might be connected for the T-type rectifier. The T-type rectifier is invaluable on the tolerant administration because of the switches in an exceedingly leg territory unit independent of each option. A few tolerant administration procedures for the open-circuit fault of the internal switch, which might be utilized in each the T-type electrical converter and rectifier, were projected in [13], [14], and [20]– [21]. These systems correction the move method to handicap the switch with the open-circuit fault and don't might want the additional devices. This paper centers around the open-circuit fault of the machine side 5L-NPC rectifier. All in all, the information currents of the 5LNPC rectifier don't flow through the external switches (Sx1 and Sx4) at solidarity power issue (pf); along these lines, the present tolerant controls for the 5L-NPC rectifier contemplate exclusively the inward switches (Sx2 andSx3) [13]. Be that as it may, per

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the detail of the PMSG, Associate in nursing open-circuit fault of the external switch will cause current distortion the maximum sum as once Associate in nursing circuit fault of the internal switch happens [22]. The tolerant administration forSx1andSx4open-circuit fault is moreover projected in [22], and this administration system infuses the exact reactive current expected to dispose of this distortion this suggests the pf is altered. Rectifiers with IPMSGs will work to concoct most power at pfs other than solidarity. IPMSGs give a great deal of power

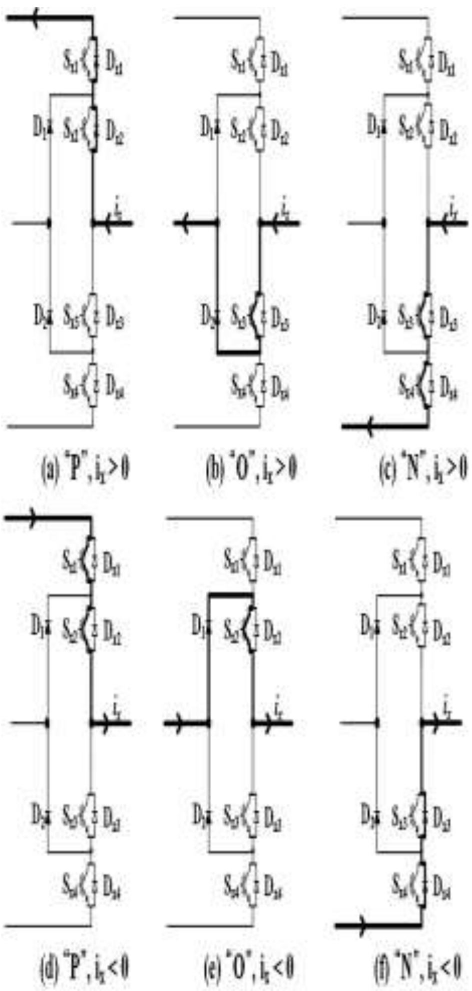

Fig. 2. Current paths depending on the current direction and the switching state.

at the point when rectifiers work at a one of a kind PF [4]– [7]. In such a case, AN open-circuit fault of the external switches (Sx1andSx4) causes current distortion and torsion vacillation, which may cause vibration of the turbine amid this paper, the clarification for this distortion caused by the external switches (Sx1 andSx4) is broke down, and after that, on the possibility of this examination, a tolerant administration forSx1 andSx4 open-circuit faults is projected inside the projected tolerant administration, the switch with AN open-circuit fault isn't wont to create the information voltages of the three-level rectifier by adding a pay worth to the reference voltages.

II WIND TURBINE

The material properties assigned to blank are shown in table 1 and the material properties assigned to remaining are considered as rigid and the schematic view of the model is shown in fig 1.

Fig1. Offshore wind farm, using 5 MW turbines REpower 5M in the North Seaoff the coast of Belgium

As a results of over a thousand years of windmill improvement and elegant building, the present wind turbines ar factory-made amid a major choice of vertical and even pivot varieties. the most diminutive turbines ar utilized for applications like battery charging for auxiliary power for water crafts or parades or to power activity cautioning signs. Marginally bigger turbines is utilized for making commitments to a residential power offer while mercantilism unused power back to the utility supplier through the electrical grid. Arrays of enormous turbines, called wind ranches, are getting partner degree more imperative supply of renewable energy and are used by a few nations as a piece of a strategy

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to curtail their dependence on non-renewable energy sources.

Windmills were used in Persia (show day Iran) concerning 500-900 A.D.[1] The windwheel of Hero of Alexandria marks one in everything about primary noted examples of wind powering a machine in history.[2][3] yet, the primary noted sensible windmills were inbuilt Sistan, relate degree japanese area of Iran, from the seventh century. These "Panemone" were vertical shaft windmills, that had long vertical drive shafts with rectangular blades.[4] produced using six to 12 sails lined in reed tangling or relic material, these windmills were wont to crush grain or draw water, and were used in the gristmilling and sugarcane industries.[5] Windmills introductory showed up in Europe all through the middle Ages. the primary authentic records of their utilization in England date to the eleventh or twelfth hundreds of years and there ar reports of German crusaders taking their windmill-production aptitudes to Syrian Arab Republic around 1190.[6] By the fourteenth century, Dutch windmills were being used to purge regions of the Rhine delta. Propelled wind factories were spoken to by Croatian artificer Fausto Veranzio. In his book Machinae Novae (1595) he spoke to vertical hub wind turbines with wiggly or shaped sharp edges.

The principal power producing turbine was electric battery charging machine place in Gregorian logbook month 1887 by Scottish instructional exercise James Blyth to light-weight his excursion go in Marykirk, Scotland.[7] Some months after the fact yank artificer Charles F. Brush could construct the primary mechanically worked turbine once counseling local University teachers and associates Jacob S. Josiah Willard Gibbs and Brinsley Coleberd and with progress getting the diagrams peer-audited for power creation inCleveland, Ohio.[7] however Blyth's rotational motor was contemplated uneconomical inside the United Kingdom[7] power generation by wind turbines was extra esteem viable in nations with wide scattered populations.[6]

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2.1 RESOURCES

2.1.1Wind Power

A quantitative live of the wind energy realistic at any area is named the wind generation Density (WPD). it's a computation of the mean yearly power reachable per zone unit of cleared space of a turning motor, and is arranged for different statures over ground. Figuring of wind power thickness incorporates the aftereffect of wind rate and air thickness. Shading coded maps ar prepared for a chose space spoke to, for instance, as "Mean Annual Power Density at fifty Meters". inside the us, the results of the over estimation ar encased in relate record created by the National Renewable Energy Laboratory and named as "NREL CLASS" The bigger the WPD, the upper it's appraised by classification. Classifications change from class one (200 watts for each territory unit or less at fifty m elevation) to classification seven (800 to 2000 watts for each sq. m) business wind cultivates ordinarily are sited at school three or higher zones, however detached points in relate generally classification one space is additionally sensible to utilize.

2.1.2EFFCIENCY

Not all the energy of handling wind is utilized, however some little wind turbines are intended to figure at low wind speeds.

Protection of mass needs that the amount of air coming into and leaving a rotating motor

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ought to be equivalent. subsequently, Betz's law offers the maximal possible extraction of wind generation by a turbine as 16/27 (59.3%) of the whole K.E. of the air flowing through the turning engine.[15] The maximum hypothetical power output of a wind machine is so zero.59 times the K.E. of the air going through the successful plate space of the machine. On the off chance that the compelling space of the plate might be an, and furthermore the wind rate v, the most extreme hypothetical power output P is: the place ρ is air thickness As wind is free (no fuel cost), wind-to-rotor intensity (counting rotational wing rubbing and drag) is one among a few angles affecting a definitive estimation of wind generation.[16] more wasteful aspects, similar to case losses, generator and gadget losses, cut back the capacity conveyed by a turbine. to protect components from undue wear, removed power is control constant over the evaluated in operation speed as hypothetical power will increment at the solid shape of wind speed, all the more decreasing hypothetical strength.

In 2001, business utility-associated turbines convey seventy fifth to eightieth of the Betz furthest reaches of power removable from the wind, at appraised in operation speed. Proficiency will diminish marginally after some time because of wear. Examination of 3128 wind turbines more seasoned than ten years in Scandinavian nation demonstrated that a large portion of the turbines had no reduction, while the inverse [*fr1] saw a generation lessening of 1.2% p.a.

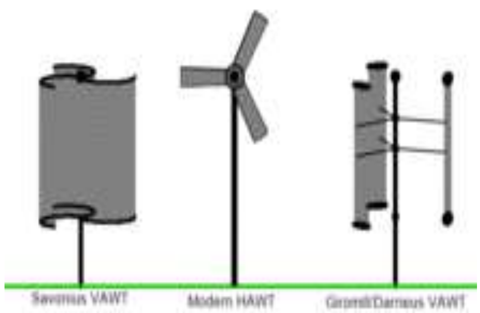

Fig2. The three primary types: VAWT Savonius, HAWT towered; VAWTDarrieus as they appear in operation

III. OPEN-CIRCUITFAULTANALYSIS OF OUTER SWITCHES

Here they are three exchanging states (P, N, and O) are content in this 5L-NPC rectifier [9]. Furthermore, contingent on the present bearing and exchanging state we can produce six current ways which is appeared in fig. 2 [23] and also below fig.3 shows the aftereffect of the info current age procedure of a rectifier alongside the unitypf. There for Irec is rectifier current, Vrec is rectifier voltage, and VEMF is back electromotive power (EMF).

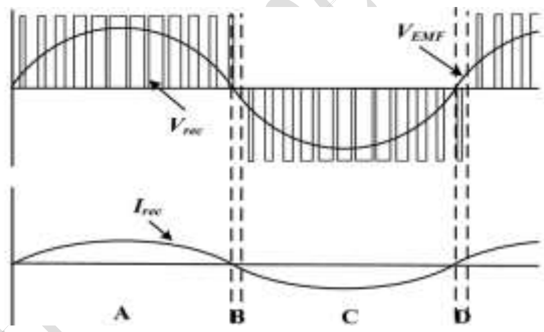

Fig.3. Rectifier operation at unity pf

Table I: Current path composition depending On the part Of Fig.3

Part	V_{rec}	I_{rec}	Current path
A	Positive	Positive	(a) P switching state, (b) O switching state (valid)
B	Positive	Negative	(d) P switching state (valid), (e) O switching state
C	Negative	Negative	(e) O switching state (valid), (f) N switching state
D	Negative	Positive	(b) O switching state, (c) N switching state (valid)

In the middle of VEMF and Vrec, the stages distinction can be causes by utilizing the present stream, which can be controlled by coordinate the period of Irec up alongside the comparing period of the VEMF. Amid the main time of Irec it has been ordered into four sections which depend on the extremity of Irec and Vrec. The present way which have been created and it is comparing diverse in light of a section, which are outlined in the above Table I. from the parts An and C, the exchanging state O which may causes the info current stream; besides it is otherwise called the substantial exchanging state.

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Here the current may persistently streams between the two diodes at whatever point the exchanging state is transformed from the P or N exchanging state at that point there will be no present streams from the switches.

In segments B and D, the P and N exchanging ranges are the honest to goodness exchanging state wherein the cutting edge moves through the switches. at the point when the rectifier works with unitypf, parts An and C are huge, and parts B and D are little. In the event that parts B and C are little as tons as be disregarded, theSx1andSx4open-circuit flaws might be overlooked [22], [23]. yet, parts B and D can be drawn out in Case I while V EMF is little and a large Irec is required [22] this is on account of the portion refinement betweenVEMFandVrec will turn out to be enormous.

In this paper, the contrary (Case II), that is the receptive present day infusion for IPMSG, is additionally contemplated. Fig. 4 demonstrates that the information front line time way of the rectifier for occasions I and II. There are segment varieties: the area contrast (ϕZ) amongst VEMF and Vrec characterized in [22], and the fragment distinction (ϕpf) amongst Iref and VEMF caused by method for the vpf. In Fig.4, component B (or segment D) incorporates ϕZ and ϕpf, and their lengths increment as a result of this the present day might be additional misshaped by utilizing the open-circuit blame of the external changes when contrasted with when ϕZ alone is considered

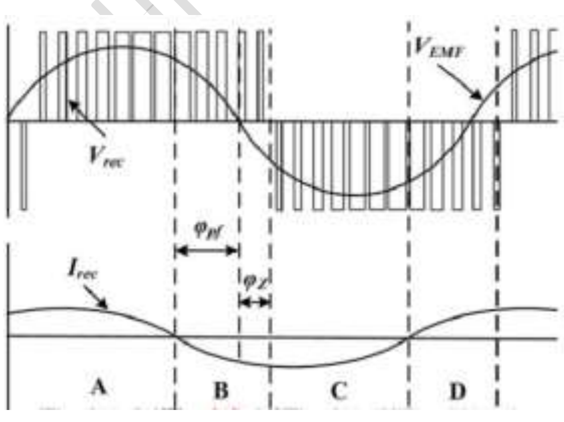

Fig. 4. Rectifier operation at any pf

Case I can be forgotten in light of the fact that ϕZ is resolved relying upon the working situation of the rectifier and the PMSG. be that as it may, due to the fact ϕpf is controlled by the pf, Case II must be considered when the IPMSG is utilized. The forefront mutilation coming about because of the open-circuit blame of the external switches is appeared in Fig. 5 for different pfs. due to the infeasible open-circuit blame switch, the present day transforms into 0 all through the range alongside Φz and ϕpf.TheSx1open-circuit blame makes the cutting edge course of Fig. 2(d).

The present course of Fig. 2(d) has a place with component B; thus, theSx1 open circuit blame causes contortion inside the negative present day as demonstrated in Fig. five(a) and (c). in actuality, the Sx4 open-circuit blame outcomes in bending inside the fine present day as appeared in Fig. 5(b) and (d) because of the reality the present heading of Fig. 2(c) identified with theSx4 open-circuit blame has a place with component D. The low pf has a huge ϕpf thus, the rectifier task at a low pf prompts a vast 0-current range while the open circuit blame of the external exchange happens accordingly the zero current range increments, in light of the fact that the pf diminishes.

The assessment related with the open-circuit blame of the external switches might be connected to the T-kind topology. The consequences of open-circuit shortcomings of the external switches at the forefront are the equivalent in both the NPC rectifier and the T-kind rectifier [13], [22] subsequently, the current bending as a result of open-circuit shortcomings of the external switches inside the NPC rectifier is like that in the T-type rectifier.

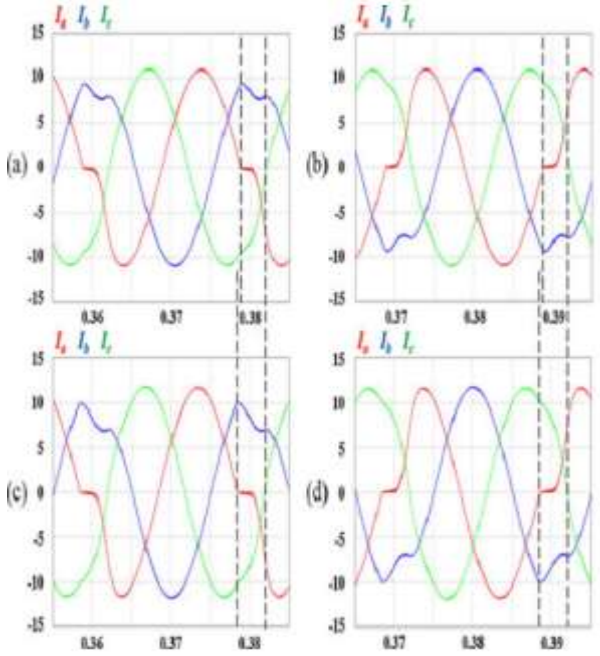

Fig. 5. Current distortion depending on the open-circuit fault and the pf:(a)0.95pf, Sx1 open-circuit fault, (b) 0.95pf, Sx4 open-circuit fault, (c) 0.9pf,Sx1 open-circuit fault, and (d) 0.9pf,Sx4 open-circuit fault

IV. TOLERANT CONTROL FOR OPEN-CIRCUIT FAULT OF OUTER SWITCHES:

Along these lines the past tolerant control technique which is for the open-circuit fault of the external switches is reactive current infusion [22]. Subsequently in this method the adjustments in the phase of Irec so which is relates alongside the Vrec phase which means that parts B and D are evacuated. Additionally the tolerant control technique may have the impediment of low-power generation proficiency of the generator on the grounds that the PMSG has effective working condition which relies upon the pf of the rectifier. By and large, the solidarity pf is required for the best working state of a surface PMSG. The best working state of an IPMSG does not compare to the solidarity pf, and this is dictated by the determinations of the IPMSG. The proposed tolerant control does not change the pf of the rectifier. The rectifier voltage (Vrec) without the present way identified with the open-circuit fault switch is created by changing the reference voltages. To clarify the proposed tolerant control, theSx1open-circuit fault is utilized for instance.

A. Compensation Voltage (V_{comp}) Calculation

Three-phase reference voltages (V x,ref, x=a, b, c)are communicated as

$$V_{a,ref} = V_{mag}\cos(2\pi f_s t)$$

$$V_{b,ref} = V_{mag}\cos\left(2\pi f_s t - {}^{2\pi}\!/_{3}\right)$$

$$V_{c,ref} = V_{mag}\cos\left(2\pi f_s t + {}^{2\pi}\!/_{3}\right) \quad \textbf{(1)}$$

Where Vmag is the greatness of the reference voltages, and fs is the fundamental frequency. The offset voltage (Voffset) is added to each reference voltage to extend the scope of the regulation index(Ma = √ 3× Vmag/Vdc). Voffset and the changed reference voltages (V x,ref, offset, x=a, b, c) are communicated as

$$V_{offset} = -{}^{\left(V_{ref,max} + V_{ref,min}\right)}\!\Big/_{2} \quad (2)$$

$$V_{a,ref,offset} = V_{a,ref} + V_{offset}$$

$$V_{b,ref,offset} = V_{b,ref} + V_{offset}$$

$$V_{c,ref,offset} = V_{c,ref} + V_{offset} \quad (3)$$

Where Vref,max and V ref,min are the maximum and least estimations of Va,ref, Vb,ref, and V c,ref. The reference voltages of (3) are contrasted with the bearer signals with create Vrec. At the point when theSx1 open-circuit fault happens, the present way of Fig. 2(d) ought to be killed to anticipate current distortion; along these lines, the reference voltage ought to be changed to produce Vrec without the present way of Fig. 2(d). In the proposed tolerant control, a reference voltage of a phase containing the Sx

Open-circuit fault is changed to zero as appeared in Fig. 6. Subsequently, the present way of Fig. 2(d) vanishes on the grounds that the O switching state is just utilized as a part of part B. To make the reference voltage zero ,|Vcomp| is alloted the extent of the reference voltage (Vx,ref, offset) containing the open-circuit fault, and Vcomp can be communicated as

V_comp=-V_(x,ref,offset) (x=a phase containing open circuited fault switch) (4)

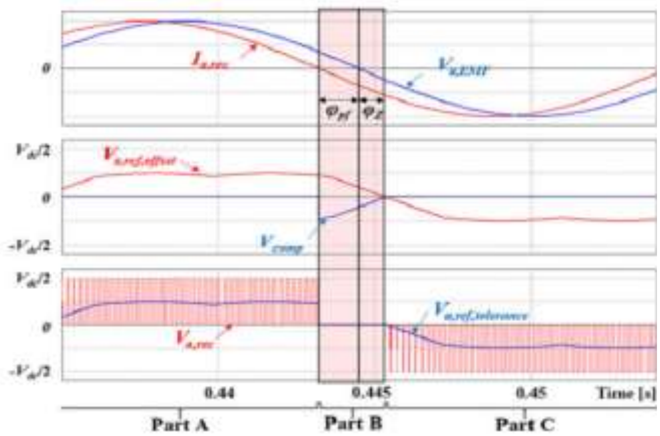

Fig. 6. Change of reference voltages in the proposed tolerant control for the Sx1 open-circuit fault (0.95pf).

The proposed tolerant control is executed by adding Vcomp to the reference voltages (Vx,ref,offset, x=a, b, c). The new reference voltages (Vx,ref,tolerance, x=a, b, c) of the proposed tolerant control are communicated as

$$V_{a,ref,tolerance} = V_{a,ref,offset} + V_{comp}$$

$$V_{b,ref,tolerance} = V_{b,ref,offset} + V_{comp}$$

$$V_{c,ref,tolerance} = V_{c,ref,offset} + V_{comp} \quad (5)$$

B. Compensation Range for Adding V_{comp}

By adding Vcomp to each reference voltage, the utilization of the present way identified with the open-circuit fault switch will be blocked. To accomplish this impeccably, Vcomp is included for the reasonable range and position. The remuneration run, which is part B or part D of Fig. 4, comprises of Φz and ϕpf. ϕZ can be figured with the proportional circuit of the PMSG and the three-level rectifier [22].ϕZ, which is the phase contrast amongst VEMF and Vrec, is communicated as

$$\varphi_z = tan^{-1}\left(\frac{-|I_{rec}|*2\pi f_s L}{V_{EMF}-|I_{ref}|R}\right) \quad (6)$$

Where R and L are the equal protection and inductance of the PMSG, and fs is the fundamental frequency speaking to the rakish frequency of the PMSG. ϕpf, which is the phase distinction amongst VEMF and Irec, is identified with the pf. ϕpf can be computed by the pf and this is

communicated as

$$\varphi_{pf} = cos^{-1}(pf) \quad (7)$$

On the off chance that the d– q control hypothesis is utilized, ϕpf can be ascertained as

$$\varphi_{pf} = cos^{-1}\left(\frac{I_{qe}}{\sqrt{I_{qe}^2+I_{de}^2}}\right) \quad (8)$$

Where Ide demonstrates the d-hub current identified with the motion and Iqe shows the q-pivot current identified with the torque, and these are values in the d– q synchronous turning outline. ϕZ and ϕpf, which are computed from (6) and (8), are situated close to the zero-intersection point of VEMF as appeared in Fig. 6. Along these lines, the pay position for including Vcomp is characterized the premise of VEMF's point (θ EMF). Fig. 7 indicates three-phase VEMFs and θ EMF. Θ EMF is obtained from the encoder or position sensor. Six zero-intersection points are communicated for each 60°, which are coordinated to each open-circuit fault as appeared in Fig. 7. Subsequently, θ EMF speaking to each zero-intersection point is a foundation for including Vcomp. For instance, when the Sa1 open circuit fault happens, Vcomp ought to be included for the pay run from(0 ◦−ϕpf)to (0 ◦+ϕZ)which is based on 0°.By considering all open-circuit faults, Table II demonstrates the pay ranges for taking out the present distortion relying upon the situation of the open-circuit fault.

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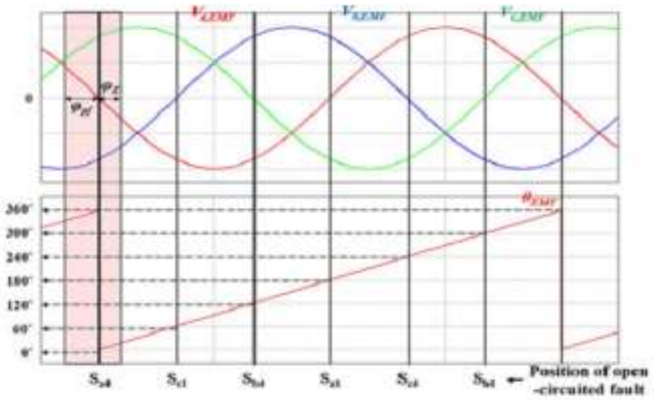

Fig. 7. Compensation position on the basis ofVEMF's angle (θEMF).

Table I I: Compensation range depending On The position of the Open-Circuit Fault

Position of open-circuit fault	Compensation range
S_{a1}	$(0° - \varphi_{pf}) \sim (0° + \varphi_Z)$
S_{c4}	$(60° - \varphi_{pf}) \sim (60° + \varphi_Z)$
S_{b1}	$(120° - \varphi_{pf}) \sim (120° + \varphi_Z)$
S_{a4}	$(180° - \varphi_{pf}) \sim (180° + \varphi_Z)$
S_{c1}	$(240° - \varphi_{pf}) \sim (240° + \varphi_Z)$
S_{b4}	$(300° - \varphi_{pf}) \sim (300° + \varphi_Z)$

C. Considering Neutral-Point Voltage Balance

The compensation voltage which is one of the offset voltages can cause objective point voltage unbalance in light of the way that Vcomp processed from (4) is an uneven voltage [10], [24]. Thusly, two dc-link capacitors have particular qualities depending upon the furthest point of Vcomp created for the open-circuit fault. The fair-minded point voltage unbalance grows the voltage weight on the switch and the present THD [24]. The proposed tolerant control for the open-circuit fault of the outer switches needs to join a response for the fair point voltage unbalance issue.

In this way, as said prior, Vcomp is included for the relating remuneration position contingent upon the situation of the open-circuit fault, and after that, Vcomp is additionally included the oppositely inverse pay position to adjust the impartial point voltage. Fig. 8 demonstrates the idea of proposed tolerant control considering the nonpartisan point voltage adjusts when the Sa1 open-circuit fault happens. In Fig. 8, Vcomp is included for the pay range [(0 ◦−ϕpf) ∼(0 ◦+ϕZ)]which compares to the situation for theSa1 open-circuit fault; furthermore, Vcomp is additionally included for the oppositely inverse pay extend [(180 ◦−ϕpf)∼(180 ◦+ϕZ)], which is the range for the Sa4 open-circuit fault. Two Vcomps included two positions have inverse extremity and these results in the adjusted unbiased point voltage. The last principles of the proposed tolerant control with the unbiased point voltage adjust are condensed in Table III.

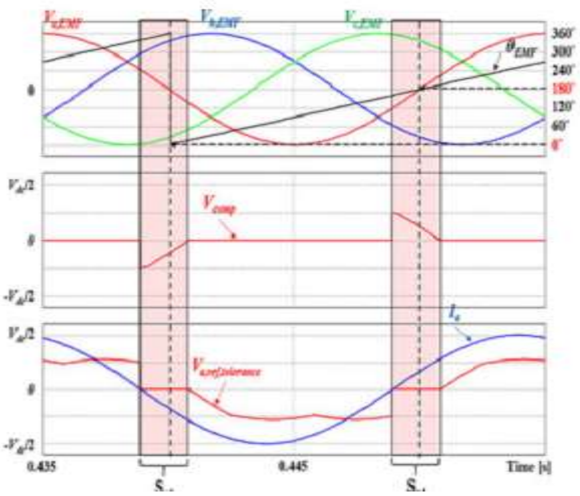

Fig. 8. Proposed tolerant control considering neutral point voltage balance under the Sa1 open-circuit fault.

TABLE III: Principle of the Proposed Tolerant Control Depending On the position of the Open-Circuit Fault

D. Limitation of Proposed Tolerant Control

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Vx,ref, resistance can't surpass a constraint voltage (Vlimit)which is confined by the dc-link voltage (Vdc). Along these lines, Vcomp is restricted as takes after,

$$V_{comp} < V_{limit} - V_{ref,max} \tag{9}$$

Position of open-circuit fault	V_{comp}	Compensation range
S_{a1} or S_{a4}	$-V_{a,ref,offset}$	$(0° - \varphi_{pf}) \sim (0° + \varphi_Z)$
S_{c4} or S_{c1}	$-V_{c,ref,offset}$	$(60° - \varphi_{pf}) \sim (60° + \varphi_Z)$
S_{b1} or S_{b4}	$-V_{b,ref,offset}$	$(120° - \varphi_{pf}) \sim (120° + \varphi_Z)$
S_{a4} or S_{a1}	$-V_{a,ref,offset}$	$(180° - \varphi_{pf}) \sim (180° + \varphi_Z)$
S_{c1} or S_{c4}	$-V_{c,ref,offset}$	$(240° - \varphi_{pf}) \sim (240° + \varphi_Z)$
S_{b4} or S_{b1}	$-V_{b,ref,offset}$	$(300° - \varphi_{pf}) \sim (300° + \varphi_Z)$

Where Vlimit is Vdc/2. Based on (9), the relevant operation scope of the proposed tolerant control is resolved relying upon Ma and thepf.Fig.9showsVx, ref, tolerance and Vcomp of the proposed tolerant control contingent upon the pf when Ma is 0.5. In Fig. 9, Vcomp prompts Va,ref, resistance with zero an incentive in the relating remuneration extend. Also, the pinnacle estimation of Vc,ref, resistance expands inferable from Vcomp.

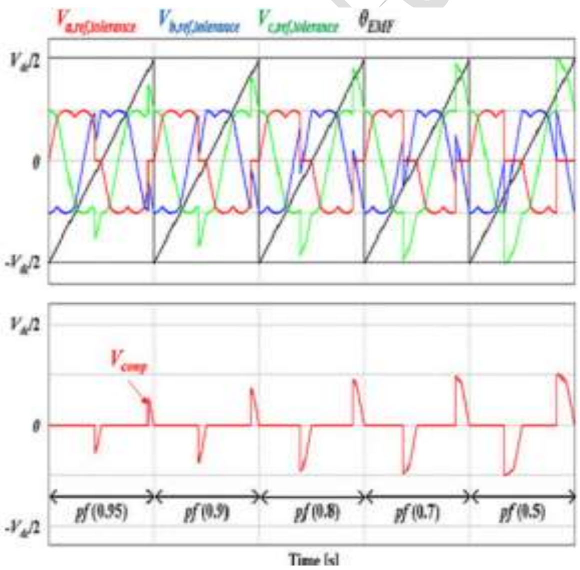

Fig.9.Vx, ref, tolerance(x=a,b,c) and Vcomp depending on the pf when Ma is 0.

As the pf diminishes, this pinnacle esteem increments; notwithstanding, it doesn't surpass Vlimit . Subsequently, whenMais littler than 0.5,Vcompcan be included paying little respect to the pf because Vc,ref, tolerance can't exceed Vlimit. At the point when Ma is bigger than 0.5, the applicable pf range is resolved by Ma. This is on the grounds that a low Ma gives an expansive edge for Vcomp; be that as it may, a large Vcomp cannot be worthy for high Ma. Fig. 10 demonstrates the applicable pf range for different qualities of Ma. The shaded piece of Fig. 10 speaks to the material operation run. The proposed tolerant control is attainable over the whole factor go when Ma is littler than 0.5. By expanding Ma from 0.5, the appropriate operation goes diminishes.

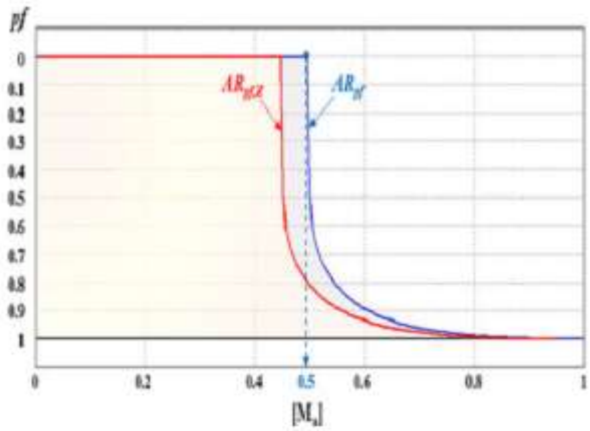

Fig. 10. Applicable pf range of the proposed tolerant control depending on Ma.

In Fig 10.the pertinent operation run appeared as ARpf is biggest when just the pf related to ϕpf is considered. In any case, a large ϕZ means that extensive part of the remuneration extend is saved for ϕZ, and the rest can be utilized to repay ϕpf. Therefore, ϕZ caused by the impedance of the PMSG diminishes the applicable pf range, and it is demonstrated in ARpf, Z with ϕZ=10. ϕZis dictated by the operation conditions and parameters of the PMSG appeared in (6). The proposed tolerant control has an impediment on its operation go that relies upon the pf and Ma.

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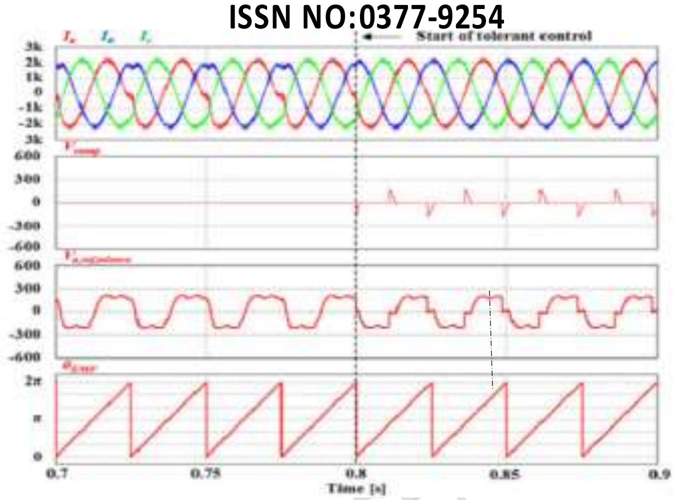
Notwithstanding, considering that wind turbine systems don't generally work with the evaluated wind speed (high Ma) and that the operating pf of the rectifier with an IPMSG isn't too low, the proposed tolerant control can unmistakably be successful.

V.RESULTS AND DISCUSSIONS:

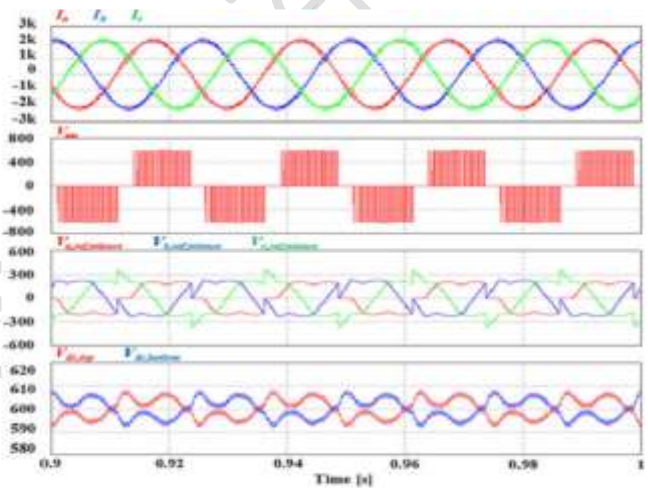
The simulation is performed misuse the PSIM apparatus. The 3L-NPC rectifier of the succeeding convertor with a couple of.5-MW IPMSG is simply thought of inside the simulation. The simulation parameters are as takes after: the switch frequency is a couple of kHz, the control sum is 250µs, the dc-link electrical condenser is 35 MF, and in this manner the dc-link voltage is 1200 V. The IPMSG parameters used in the simulation are appeared in Table IV. The arranged tolerant administration for the open-circuit fault of the external switches (Sx1, Sx4) is upheld for different pfs and generator speeds. Fig. 11 demonstrates the simulation results of the arranged tolerant administration once the Sa1 open-circuit fault happens.

TABLE IV: IPMSG PARAMETERS INSIMULATION

Rated power	2.5 MW
Number of pole	8
Rated voltage (line-to-line)	760 V_{rms}
Rated current	1902 A_{rms}
Rated speed	1650 rpm
Resistance	0.4567 mΩ
q-inductance	0.0982 mH
d-inductance	0.0725 mH



(a)



(b)

Fig. 11. Simulation results with the proposed tolerant control under the Sa1 open-circuit fault (600 rpm,Ma =0.35,0.95pf).

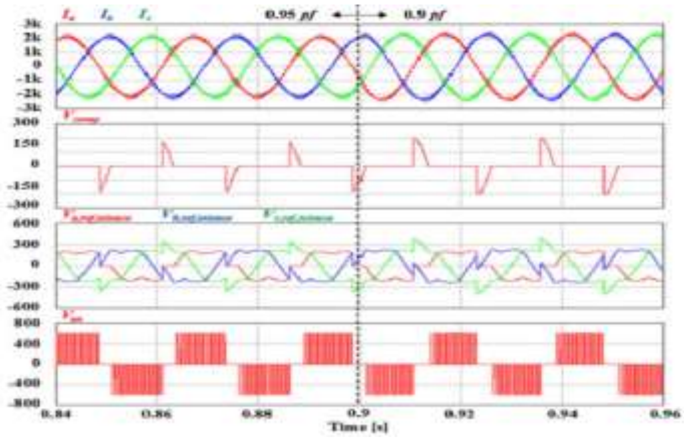


Fig. 12. Simulation results with the proposed tolerant control under theSa1 open-circuit fault (600 rpm, Ma =0.35, pf-transition from 0.95 to 0.9).

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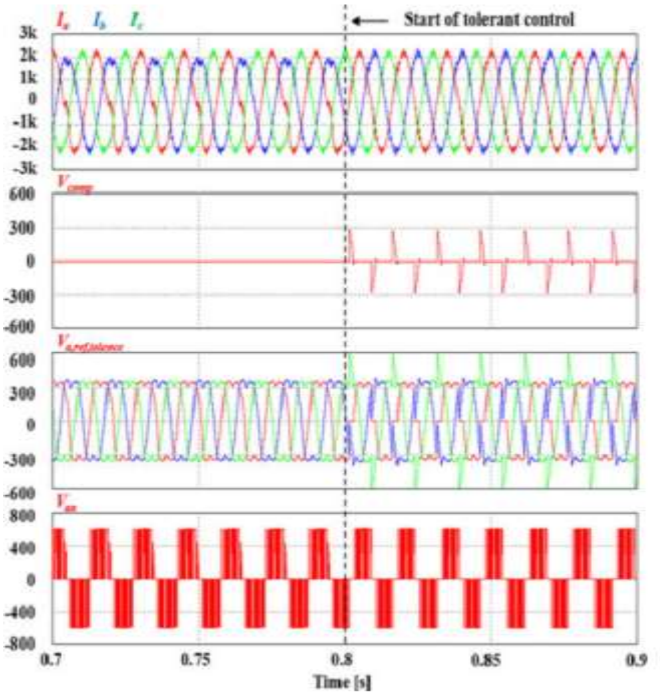
The speed of the PMSG is 600 rpm, Ma is 0.35, and in this manner the pf of the rectifier is 0.95 because of the Sa1 open-circuit fault, the negative current is contorted as appeared in Fig. 11(a). once the arranged tolerant administration is connected, the reference voltages are adjusted by Vcomp for the relating ranges which are outlined in Table III. Therefore, the a-phase post voltage (Van) is clipped to 0 at their extents as appeared in Fig. 11(b) and the present distortion is wiped out totally.



. Fig. 13. Simulation results with the proposed tolerant control under theSa1 open-circuit fault (1000 rpm, Ma =0.59, 0.95pf)

In this manner, moreover, the 2 dc-link capacitance voltages are adjusted. The projected tolerant administration is successful for the pf transition operation of the rectifier. Fig. 12 demonstrates the results once the projected tolerant administration is connected and the pf is changed from zero.95 to 0.9. The remuneration differ is expanded the maximum sum in light of the fact that the pf decreases and in this manner the currents are maintained while not distortion unendingly. Besides, we as a whole realize that the tallness value of Vc,ref, tolerance ends up mammoth because of the pf decreases that was said in Section III. Fig. 13 demonstrates the execution of the projected tolerant administration underneath the Sa1 open-circuit fault at totally extraordinary speed (1000 rpm) of the PMSG when Ma is 0.59 much the same as Fig. 11, the mutilated currents are rectified once the projected tolerant administration is connected. In any case, the stature value of Vc,ref, tolerance is closed to Vlimit (Vdc/2)at 0.95pf, that is totally not quite the same as what's appeared in Fig. 11. this is regularly because Ma of Fig. thirteen envelops a smaller applicable operation fluctuating than that of Fig. 11, which may be found in Fig. 10. Table V demonstrates this THD results previously and once the projected tolerant administration is connected. this THD is raised by the Sa1 open-circuit fault; in any case, on account of the projected tolerant administration, this THD is restored practically in the same class as customary state with none open-circuit fault.

VI. CONCLUSION

In this paper the proposes system is spoken to by a tolerant control for the open-circuit fault alongside the external switches in the three-level rectifiers (both 3L-NPC and T-type topologies)which is used in the wind turbine systems. Consequently the real motivation behind why the tolerant control for the open-circuit fault alongside the external switches in the three-level rectifiers is required for the introduced, together alongside the help. Which is relying on the investigation of a tolerant control for each open-circuit fault which is recommended that assesses the unbiased point voltage adjusts. This control is created by including of a remuneration voltage (Vcomp) alongside the reference voltages for the relating pay ranges which is based upon the situation of the open-circuit fault. Additionally , this control strategy can likewise be utilized as a part of two routes, for example, the 3L-NPC and T-type rectifiers and furthermore the ensures ordinary operation no difference in the pfin . thusly the material operation run as appeared in Fig. 10 which is based upon the adjustment record (Ma) and the pf. in spite of the fact that the working scope of the proposed tolerant control which is liable to a constraint, accepting that wind turbine systems cannot work dependably with appraised wind speed and consequently that the working pf of the rectifier alongside an IPMSG isn't bring down, the proposed tolerant control might be obviously viable.

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