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Operation of Doubly Fed Induction Generator (DFIG) With an Integrated Active Filter Capabilities Using Grid-Side Converter (GSC)

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Abstract:

This paper manages the operation of doubly fed induction generator (DFIG) with an incorporated dynamic channel abilities utilizing matrix side converter (GSC). The fundamental commitment of this work lies in the control of GSC for supplying sounds notwithstanding its slip power exchange. The rotor-side converter (RSC) is utilized for accomplishing most extreme force extraction and to supply required receptive energy to DFIG. This wind vitality transformation framework (WECS) acts as a static compensator (STATCOM) for supplying music notwithstanding when the wind turbine is in closed down condition. Control calculations of both GSC and RSC are displayed in point of interest. The proposed DFIG-based WECS is reenacted utilizing MATLAB/Semolina. A model of the proposed DFIG-based WECS is produced utilizing a computerized signal processor (DSP). Mimicked results are approved with test aftereffects of the created DFIG for various down to earth conditions, for example, variable wind speed and unequal/single stage burdens.

Index Terms:

Doubly fed induction generator (DFIG),integrated active filter, nonlinear load, power quality, wind energy conversion system (WECS).

I. INTRODUCTION:

With the expansion in populace and industrialization, the vitality request has expanded significantly. However, the customary vitality sources, for example, coal, oil, and gas are constrained in nature. Presently, there is a requirement for restore capable vitality hotspots for the future vitality request [1]. The other fundamental points of interest of this renewable source are eco-cordiality and boundless in nature [2]. Because of specialized progressions, the expense of the wind power delivered is tantamount to that of traditional force plants. Hence, the wind vitality is the most favored out of all renewable vitality sources [3]. In the underlying days, wind turbines have been utilized as settled pace wind turbines with squirrel confine instigation generator and capacitor banks. The vast majority of the wind turbines are altered rate as a result of their effortlessness and ease [4]. By watching wind turbine attributes, one can unmistakably recognize that for separating most extreme power, the machine ought to keep running at different rotor speeds at various wind speeds. Utilizing present day power electronic converters, the machine can keep running at customizable paces [5]. In this way, these variable pace wind turbines can enhance the wind vitality creation [6]. Out of all variable velocity wind turbines, doubly bolstered prompting generators (DFIGs) are favored as a result of their minimal effort [7]. The other advantages of this DFIG are the higher vitality yield, lower converter rating, and better use of generators [8]. These DFIGs additionally give great damping execution to the feeble lattice [9].

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Autonomous control of dynamic and receptive force is accomplished by the decoupled vector control calculation exhibited in [10] and [11]. This vector control of such framework is typically acknowledged in synchronously pivoting reference outline situated in either volt-age hub or flux hub. In this work, the control of rotor-side converter (RSC) is actualized in voltage-arranged reference outline. Grid code requirements for the grid connection and operation of wind farms are discussed in [12]. Response of DFIG-based.

TABLE I: [35]CURRENT DISTORTION LIMITS FOR GENERAL DISTRIBUTION SYSTEMS IN TERMS OF INDIVIDUAL HARMONICS ORDER (ODD HARMONICS) [35]

I_{sc}/I_L	<11	11 ≤ h ≤17	17 ≤ h ≤ 23	23 ≤ h ≤ 35	35 ≤ h	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10	4.5	4.0	1.5	0.7	12
100 < 1000	12	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Maximum harmonic current distortion is in percent of I_L. I_{sc}= maximum short-circuit current at PCC; I_L=maximum demand loadcurrent (fundamental frequency component) at PCC. wind vitality transformation framework (WECS) to network aggravation is contrasted with the settled velocity WECS in [13]. As the wind infiltration in the framework gets to be critical, the utilization of variable pace WECS for supplementary occupations, for example, power smoothen-ing and consonant relief are necessary notwithstanding its energy era. This force smoothening is accomplished by including super attractive energy storage frameworks as proposed in [14]. The other assistant administrations, for example, receptive force prerequisite and transient security farthest point are accomplished by includ-ing static compensator (STATCOM) in [15]. A dissemination STATCOM (DSTATCOM) combined with fly-wheel vitality stor-age framework is utilized at the wind ranch for alleviating music and recurrence aggravations [16].

Nonetheless, the creators have utilized two all the more additional converters for this reason. A super capacitor vitality stockpiling framework at the dc connection of bound together power quality conditioner (UPQC) is proposed in [17] for enhancing power quality and unwavering quality. In every above technique [15]–[17], the creators have utilized separate converters for remunerating the harmonics furthermore to control the responsive force. Nonetheless, in later stages, a portion of the analysts have altered the control calculations of as of now existed DFIG converters for relieving the force quality issues and responsive force pay [18]–[26]. The music remuneration and responsive force control are accomplished with the assistance of existing RSC [18]–[23]. Along these lines, sounds are infused from the RSC into the rotor windings. This makes misfortunes and commotion in the machine. These distinctive music in turning part may likewise make mechanical unbalance. Besides, both receptive force remuneration and symphonious pay are accomplished in every one of these techniques utilizing RSC control.

These techniques increment the RSC rating. In [24] and [25], consonant remuneration and responsive force control are done utilizing GSC. In this way, the music are not going through machine windings in every one of these cases. Todeschini and Emanuel [26] have looked at three changed control algorithms lastly presumed that joined tweak of both RSC and GSC are required for repaying the sounds and controlling the receptive force. In any case, the creators have utilized direct current control of GSC. Hence, consonant compensation is not all that compelling and aggregate symphonious mutilation (THD) is at the very least 5% according to IEEE-519 standard given in Table I. The creators have additionally not checked reproduction comes about tentatively. A circuitous current control strategy is straightforward and indicates better execution for dispensing with music when contrasted with direct current control [27]–[30].In this work, another control calculation for GSC is expert postured for remunerating sounds created by nonlinear burdens utilizing a roundabout current control.

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RSC is utilized for control-ling the responsive force of DFIG. The other primary preferred standpoint of proposed DFIG is that it functions as a dynamic channel notwithstanding when the wind turbine is in shutdown condition. In this way, it repays load receptive force and sounds at wind turbine slowing down case. Both reenactment and trial per-formances of the proposed incorporated dynamic channel based DFIG are displayed in this work. The dynamic execution of the proposed DFIG is likewise shown for shifting wind speeds and changes in uneven nonlinear burdens at purpose of regular coupling (PCC).

II.SYSTEM CONFIGURATION AND OPERATING PRINCIPLE

In this work, another control calculation for GSC is expert postured for remunerating sounds created by nonlinear burdens utilizing a roundabout current control. RSC is utilized for control-ling the responsive force of DFIG. The other primary preferred standpoint of proposed DFIG is that it functions as a dynamic channel notwithstanding when the wind turbine is in shutdown condition. In this way, it repays load receptive force and sounds at wind turbine slowing down case. Both reenactment and trial performances of the proposed incorporated dynamic channel based DFIG are displayed in this work. The dynamic execution of the proposed DFIG is likewise shown for shifting wind speeds and changes in uneven nonlinear burdens at purpose of regular coupling (PCC).

III.DESIGN OF DFIG-BASED WECS:

Determination of appraisals of VSCs and dc-join voltage is especially essential for the effective operation of WECS. The appraisals of DFIG and dc machine utilized as a part of this exploratory framework are given in Appendix. In this area, a nitty gritty outline of VSCs and dc-join voltage is examined for the exploratory framework utilized as a part of the research center.

A. Selection of DC-Link Voltage:

Normally, the dc-link voltage of VSC must be greater than twice the peak of maximum phase voltage.

The determination of dc-connection voltage relies on upon both rotor voltage and PCC voltage. While considering from the rotor side, the rotor voltage is slip times the stator voltage. DFIG utilized as a part of this model has stator to rotor turns proportion as 2:1. Regularly, the DFIG working slip is±0.3. Along these lines, the rotor voltage is constantly not exactly the PCC voltage. So, the outline criteria for the choice of dc-connection voltage can be accomplished by considering just PCC voltage. While considering

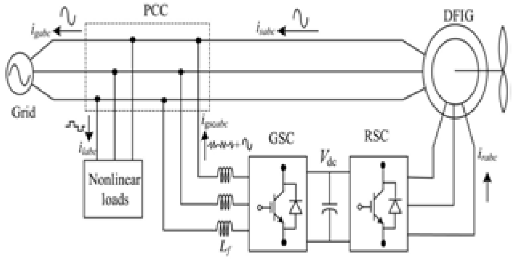

Fig. 1. Proposed system configuration.

From the GSC side, the PCC line voltage (v_{ab}) is 230 V, as the machine is connected in delta mode.

B. Selection of VSC Rating:

The DFIG draws a slacking volt-ampere receptive (VAR) for its excitation to manufacture the evaluated air crevice voltage. It is figured from the machine parameters that the slacking VAR of 2 kVAR is required when it is running as an engine. In DFIG case, the oper-ating speed extent is 0.7 to 1.3 p.u. In this manner, the most extreme slip (smax) is 0.3. For making solidarity power variable at the stator side, receptive force of 600 VAR (Smax∗Qs= 0.3 ∗ 2 kVAR) is required from the rotor side (Qrmax). The greatest rotor dynamic force is (Smax∗P). The force rating of the DFIG is 5 kW. In this way, the most extreme rotor dynamic force (Prmax) is 1.5 kW (0.3 ∗ 5 kW = 1.5 kW).

C. Design of Interfacing Inductor:

The outline of interfacing inductors amongst GSC and PCC relies on admissible GSC current point of confinement (igscpp), dc-join voltage, and exchanging recurrence of GSC. Most extreme possi-ble GSC line streams are utilized for the figuring.

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Most extreme line current relies on the greatest force and the line voltage at GSC. The most extreme conceivable force in the GSC is the slip power. For this situation, the slip force is 1.5 kW.

IV. CONTROL STRATEGY:

Control algorithms for both GSC and RSC are presented in this section. Complete control schematic is given in Fig. 2. The control algorithm for emulating wind turbine characteristics using dc machine and Type A chopper is also shown in Fig. 2.

A. Control of RSC:

The fundamental reason for RSC is to concentrate most extreme force with free control of dynamic and receptive forces. Here, the RSC is controlled in voltage-situated reference outline. Accordingly, the dynamic and responsive forces are controlled by controlling direct and quadrature hub rotor streams (idr and iqr), separately. Direct pivot reference rotor current is chosen with the end goal that most extreme force is extricated for a specific wind speed. This can be accomplished by running the DFIG at a rotor speed for a specific wind speed.

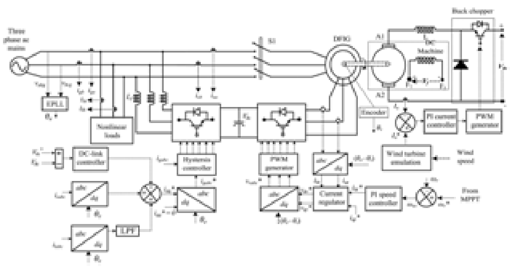

Fig. 2. Control algorithm of the proposed WECS.

The tuning of PI controllers utilized as a part of both RSC and GSC are accomplished utilizing Ziegler Nichols strategy. At first, kid quality is set to zero and the estimation of kpd was expanded until the reaction stars wavering with a time of Ti. Presently, the estimation of kpd is taken as 0.45 kpd and child is taken as 1.2 kpd/Ti.Normally, the quadrature pivot reference rotor current (i∗qr) is chosen with the end goal that the stator responsive force (Qs) is made zero. In this DFIG, quadrature pivot reference rotor current (i∗ qr) is chosen for infusing the required responsive force. Inward present control circles are taken for control of real immediate and quadrature pivot rotor streams (idr and iqr) near the direct and quadrature hub reference rotor ebbs and flows (i∗ dr and i∗ qr). The rotor streams idr and iqr are computed from the detected rotor ebbs and flows (ira, irb, and irc) as [32]

B. Control of GSC:

The novelty of this work lies in the control of this GSC for mitigating the harmonics produced by the nonlinear loads.

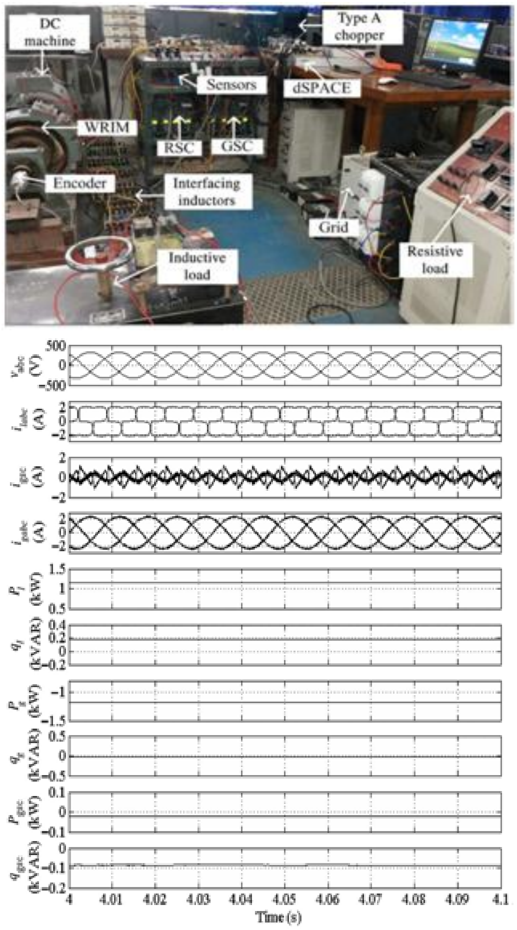

Fig. 3. Photograph of a prototype of DFIG system.

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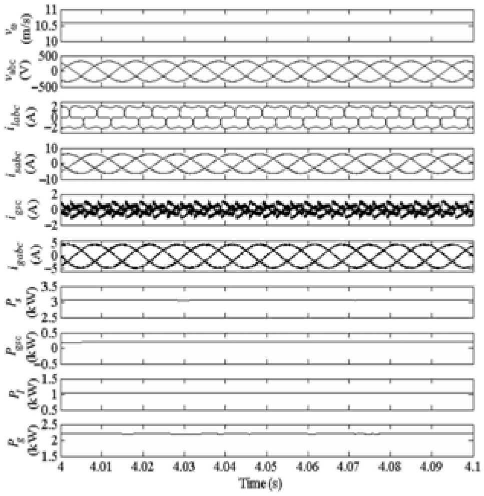

Fig. 4. Simulated performance of the proposed DFIG-based WECS at fixed wind speed of 10.6 m/s (rotor speed of 1750 rpm).

The control piece outline of GSC is appeared in Fig. 2. Here, an aberrant current control is connected on the matrix streams for making them sinusoidal and adjusted. Thusly, this GSC sup-handles the sounds for making framework streams sinusoidal and adjusted. These network streams are ascertained by subtracting the heap ebbs and flows from the summation of stator ebbs and flows and GSC ebbs and flows. Dynamic force part of GSC current is acquired by handling the dc-join voltage mistake (vdce) between allude ence and assessed dc-join voltage (Vdc∗ and Vdc) through PI controller as

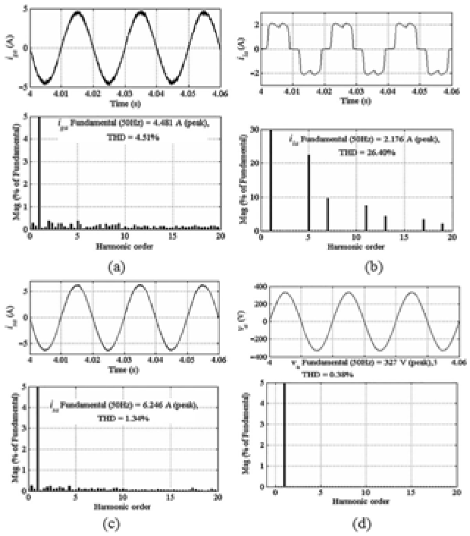

Fig. 5. Simulated waveform and harmonic spectra of (a) grid current (iga), (b) load current (ila), (c) stator current (isa), and (d) grid voltage for phase “a” (vga) at fixed wind speed of 10.6 m/s (rotor speed of 1750 rpm).

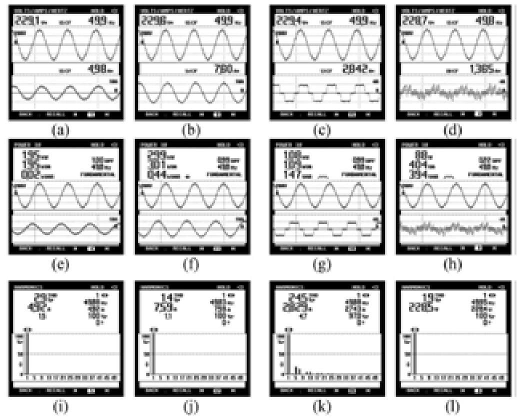

Fig. 6. Performance of the proposed DFIG-based WECS at fixed wind speed of 10.6 m/s (rotor speed of 1750 rpm (a) vab, iga; (b) vab, isa; (c) vab, ila; (d) vab, igsca; (e) Pg; (f) Ps; (g) Pl; (h) PGSC; and harmonic spectra of (i) iGa, (j) isa, (k) ila, and (l) vab.

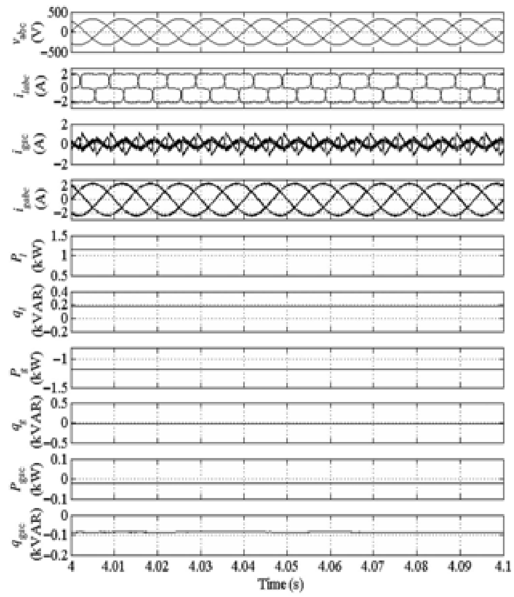

Fig.7. Simulated performance of the proposed DFIG-based WECS working as a STATCOM at zero wind speed.

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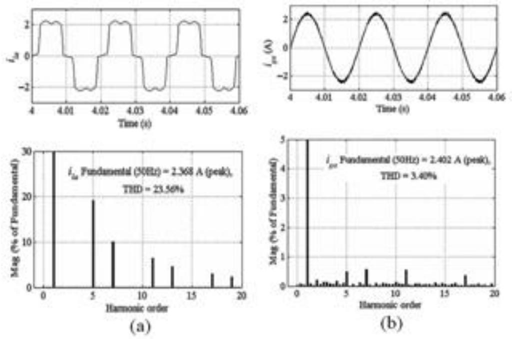

Fig. 8. Simulated waveforms and harmonic spectra of (a) load current (ila) and (b) grid current (iga) working as a STATCOM at wind turbine shut down condition.

Fundamental active load current (i_{ld}) is obtained using SRF theory [33]. Instantaneous load currents (i_{labc}) and the value of phase angle from EPLL are used for converting the load chronously rotating frames, fundamental frequency currents are converted into dc quantities and all other harmonics are con-verted into non-dc quantities with a frequency shift of 50 Hz. DC values of load currents in synchronously rotating dq frame (i_{ld}) are extracted using low-pass filter (LPF).

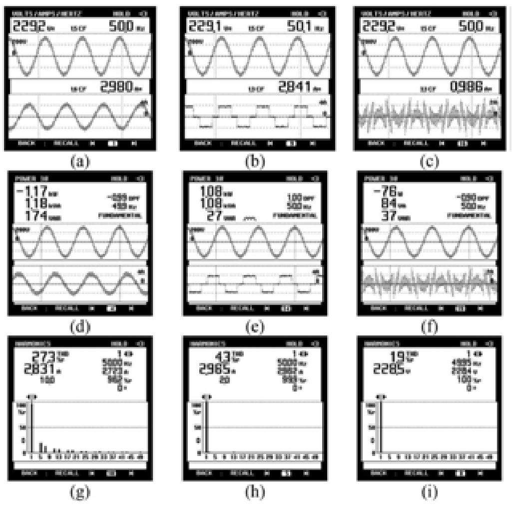

Fig. 9. Performance of the proposed DFIG-based WECS working as aSTATCOM at zero wind speed (a) vab, iga; (b) vab, ila; (c) vab, igsca; (d) Pg; (e) Pl; (f) PGSC; and harmonic spectra of (g) ila, (h) iga, and (i) vab.

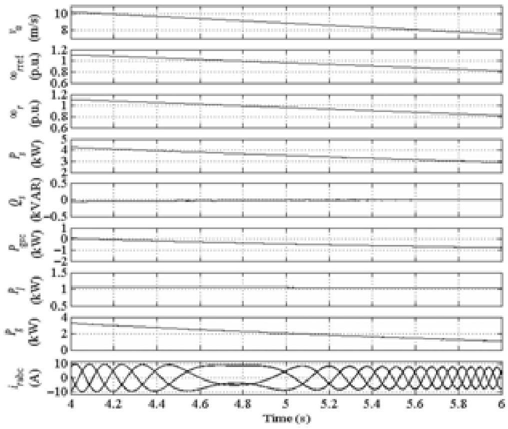

Fig. 10. Simulated performance of proposed DFIG for fall in wind speed

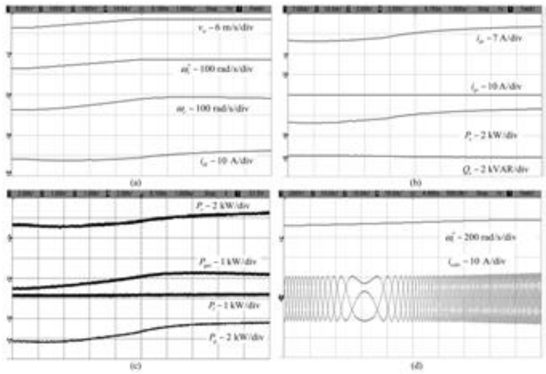

Fig. 11. Dynamic performance of DFIG for the rise in wind speed: (a) v_w, ω_r^*, ω_r, and i_{dr}; (b) i_{dr}, $i_{qr}$$P_s$, and Q_s; (c) P_s, P_{gsc}, P_l, and P_g ; and (d) ω_r^* , i_{ra}, i_{rb}, and i_{rc}.

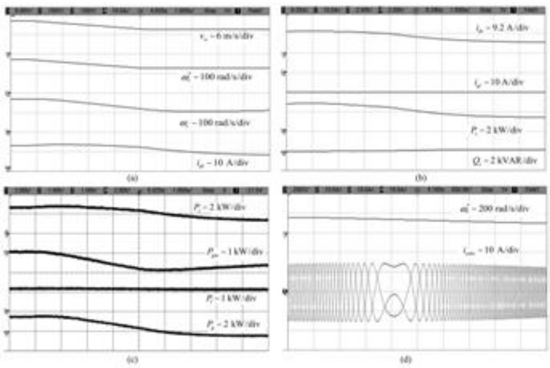

Fig. 12. Dynamic performance of DFIG-based WECS for fall in wind speed: (a) v_w , ω_r^* , ω_r , and i_{dr}; (b) i_{dr}, i_{qr}, P_s, and Q_s; (c) P_s, P_{gsc}, P_l, and P_g ; and (d) ω_r^* , i_{ra}, i_{rb}, and i_{rc}.

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Quadrature axis component of reference grid current (i^*_{gq}) is selected as zero for not to draw any reactive power from grid. Reference grid currents (i^*_{ga}, i^*_{gb}, and i^*_{gc}) are calculated from the direct and quadrature axis grid currents (i^*_{gd}, i^*_{gq}) [32]. The hysteresis current controller is used to generate switching pulses for the GSC. The hysteresis controller is a feedback cur-rent control where sensed current tracks the reference current within a hysteresis band (i_{hb}) [34]. At every sampling instant, the actual current (i_{gabc}) is compared to the reference current (i^*_{gabc}) as

V.EXPERIMENTAL IMPLEMENTATION AND OPERATINGSEQUENCE:

A model of the DFIG-based WECS with coordinated dynamic channel abilities is created utilizing DSP (dSPACE DS1103) in the research center. A photo of model is appeared in Fig. 3. In this trial framework, DFIG is combined with a dc machine. Wind turbine qualities are copied utilizing Type A hack for every and a dc machine. The dc machine flux is made consistent by keeping the field voltage steady. In this manner, the torque of the machine is controlled by controlling the armature current. The torque of the dc machine is chosen from the wind turbine singe acteristics for a specific wind speed and the rotor speed. The armature current is ascertained from the requested torque utilizing flux steady (kφ).

The obligation proportion of the chopper is gotten from the present controller. At first, the stator of the DFIG is kept secluded from the matrix utilizing switch S1 and the dc machine keeps running at consistent rate by giving settled obligation proportion to the chopper. The GSC is controlled for keeping up the voltage at the dc join. At first, this GSC works like a straightforward dynamic channel for supplying the responsive force and sounds of the nearby nonlinear burdens. Presently, this RSC is made ON for making the voltage of the DFIG same as the network volt-age by changing the responsive segment of rotor current (iqr). A dynamic force segment of rotor current (idr) is ensured that the stator voltage and the network voltage are in same stage. Presently, the switch S1 is made ON. The control of dc machine is changed from altered obligation proportion mode to wind tur-bine mode. Still, as there is no dynamic force stream from DFIG to matrix, the pace of the machine slopes to greatest contingent on the inactivity of the machine. Presently, the pace controller is actuated. In this manner, the machine speed settles to the reference speed and the dynamic force is encouraged to the lattice.

VI. RESULTS AND DISCUSSION:

Both simulated and experimental results are presented in this section for validating steady-state and dynamic performances of this proposed DFIG with integrated active filter capabilities.

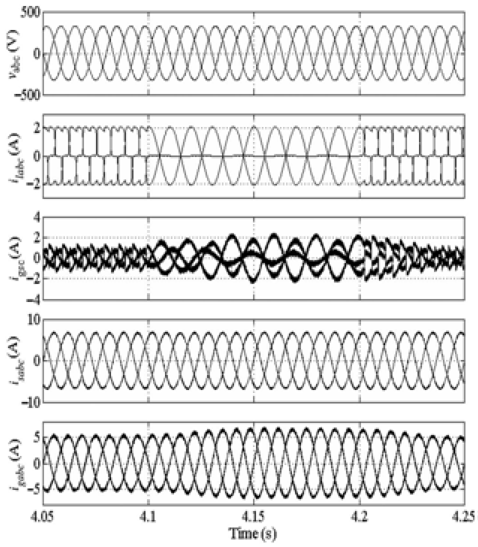

Fig. 13. Dynamic performance of DFIG-based WECS for the sudden removal and application of local loads.

In this section, the working of this proposed GSC is presented as an active filter even when the wind turbine is in shutdown condition. The power that is coming into the PCC through GSC is considered as positive in this paper.

A. Steady-State Performance of DFIG-Based WECS With Integrated Active Filter Capabilities:

The reenacted execution of this proposed DFIG is pre-sented at a 10.6-m/s wind speed as appeared in Fig. 4.

As the proposed DFIG is working at MPPT, the reference velocity of the DFIG is chosen as 1750 rpm. The heap streams are seen to be nonlinear in nature. The GSC is supplying required harmonics streams to the heap for making matrix ebbs and flows (igabc) and stator ebbs and flows (isabc) adjusted and sinusoidal. Fig. 4 likewise demonstrates the stator power (Ps), GSC power (Pgsc), load power (Pl), and lattice power (Pg). At above synchronous rate, the force stream is from the GSC to PCC, so the GSC force is appeared as positive. Complete force delivered by the DFIG is the total of stator force (Ps) and GSC power (Pgsc). In the wake of nourishing energy to the heap (Pl), the rest of the force is bolstered to the lattice (Pg). Fig. 5 (a)–(d) indicates consonant spectra and waveforms of framework current (iga), load current (ila), stator current (isa), and network voltage (vga), separately. From these symphonious spectra, one can comprehend that lattice current and stator current THDs are under 5% according to IEEE-519 standard [35] limits given in Table I. Fig. 6 demonstrates test comes about by performing tests on the created model at a settled wind velocity of 10.6 m/s.

These test outcomes are watched like the reproduced comes about. Fig. 7 shows Fig. 7 demonstrates the recreated aftereffects of GSC filling in as a dynamic channel notwithstanding when the wind turbine is in slow down condition. Here, stator streams are zero, as there is no force produc-tion from the DFIG. The heap force is supplied from the lattice. Along these lines, the lattice power (Pg) is seen to be negative. Presently, this GSC supplies sounds streams and receptive force. In this way, the receptive force taken from the matrix (Qg) is seen to be zero. Lattice streams are seen to be adjusted and sinusoidal even load ebbs and flows are nonlinear. Fig. 8 indicates consonant spec-tra of burden current and matrix current. Indeed, even the heap current THD is high, lattice current THD is under a point of confinement of IEEE-519 standard. Fig. 9 demonstrates the test outcomes when GSC is filling in as a dynamic channel when DFIG is in slow down condition. These test outcomes are additionally watched like recreation results.

Fig. 9(a)–(c) demonstrates the framework current (iga), load current (ila), and GSC mongrel rent (igsca) with line voltage (vab). Matrix current (iga) THD is seen to be under 5% even in test outcomes

B. Dynamic Performance of DFIG-Based WECS With Integrated Active Filter Capabilities Reenacted and test exhibitions of the proposed DFIG-based WECS are introduced for the variety in wind speeds, sudden evacuation of one period of nearby load, furthermore sudden use of one period of a neighborhood load. Fig. 10 demonstrates the reproduction comes about for a diminishing in wind speed. The reference speed (ωrref) is diminished with the reduction in wind speed (vw) for accomplishing MPPT operation. The real rotor velocity of the DFIG (ωr) is additionally diminished with the reference speed. With the decline in wind speed, the rotor speed (ωr) of the DFIG is diminished from super-synchronous velocity to the sub synchronous speed furthermore the slip of the DFIG gets to be certain from negative. In this way, the force stream in the rotor is switched. Already, the rotor sup-employs power through GSC into the matrix. As the velocity comes to beneath synchronous rate, the rotor begins taking force from GSC into the rotor.

Thusly, the GSC force is getting to be negative. The heap force is taken as consistent for this situation. At high wind speeds, the overabundance force is nourishing to the framework subsequent to supplying to the nearby load. As the wind speed diminishes, the force generated by the DFIG is not adequate to nourish neighborhood loads. Consequently, the heap is supplied from the matrix. In this way, the framework power (Pg) switches its course. As the velocity changes from super-synchronous pace to the sub synchronous speed, the adjustment in the stage grouping of the rotor streams is watched. Figs. 11 and 12 show test comes about for exhibiting the dynamic execution of the proposed DFIG for an expansion and lessening in wind speed, separately. The immediate pivot segment of rotor current (idr), which is in charge of the era of dynamic force, should be expanded with an expansion in wind speed for extricating more

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power. As appeared in Fig. 11(b), with an expansion in wind speed, the immediate hub rotor current (idr) is expanding, so the stator dynamic force (Ps) is additionally increasing. From Fig. 11(b), one can unmistakably watch that quadrature pivot rotor current (iqr) is kept steady to keep stator receptive force (Qs) zero. Subsequently, the entire charging current of the DFIG is supplied by the RSC. Henceforth, the stator is practically kept up at solidarity power component by the RSC. Test brings about Fig. 12 are seen to be like the mimicked comes about. Fig. 13 demonstrates the recreated execution for showing the heap pay capacity of the proposed DFIG. This unequal burden is copied by all of a sudden evacuating one period of a heap. From the outcomes, one can unmistakably watch that the stator and lattice streams are seen to be adjusted and sinusoidal notwithstanding for the uneven burden. Fig. 13 demonstrates the dynamic execution of this proposed DFIG-based WECS for the sud-sanctum expulsion and use of burden on stage "an." Even for the uneven or single stage loads, the stator and network streams are adjusted and sinusoidal by remunerating the stage "a" mutt rent through GSC. GSC current (igsca) in stage "an" is expanded all of a sudden for adjusting network streams. An expansion in framework dog rents (igabc) is seen as net burden diminishes with evacuation of one stage. Figs. 14 and 15 demonstrate the test aftereffects of the proposed DFIG for sudden evacuation and infusion of burden on stage "a," respec-tively. Test results are seen to be verging on like the mimicked comes about.

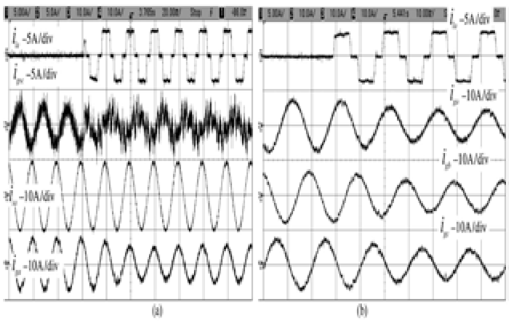

Fig. 14. Dynamic performance of DFIG-based WECS for the sudden injection of one phase of local load. (a) i_{la}, i_{gsca}, i_{sa}, and i_{ga}. (b) i_{la}, i_{ga}, i_{gb}, and i_{gc}.

VII. CONCLUSION:

The GSC control calculation of the proposed DFIG has been changed for supplying the music and receptive force of the nearby loads. In this proposed DFIG, the receptive force for the impelling machine has been supplied from the RSC and the heap responsive force has been supplied from the GSC. The decoupled control of both dynamic and receptive forces has been accomplished by RSC control. The proposed DFIG has likewise been checked at wind turbine slowing down condition for repaying sounds and receptive force of neighborhood burdens. This proposed DFIG-based WECS with an incorporated dynamic channel has been mimicked utilizing MATLAB/Simulink environment, and the reproduced results are checked with test consequences of the created model of this WECS. Enduring state execution of the proposed DFIG has been shown for a wind speed. Dynamic execution of this proposed GSC control calculation has additionally been checked for the variety in the wind speeds and for neighborhood nonlinear burden.

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