International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-10 Issue-2, December 2020

Control & Design for FOPID Based Line-Side Converter of the Brushless Doubly-Fed Induction Generator

Hazara Begum, K. Sandhya Rani, V. V. Manga Lakshmi Chinni

Abstract-This paper deals with the operation of doubly fed induction generator (DFIG) with an integrated active filter capabilities using grid-side converter (GSC). The main contribution of this work lies in the control of GSC for supplying harmonics in addition to its slip power transfer. The rotor-side converter (RSC) is used for attaining maximum power extraction and to supply required reactive power to DFIG. This wind energy conversion system (WECS) works as a static compensator (STATCOM) for supplying harmonics even when the wind turbine is in shutdown condition. Control algorithms of both GSC and RSC are presented in detail. The proposed DFIG-based WECS is simulated using MATLAB/Simulink.

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

I. INTRODUCTION

Wind ower is the conversion of wind energy into a suitable form of energy, such as using wind turbines to generate electricity, windmills for mechanical ower, wind pumps for water pumping, or sails to propel ships. The total amount of economically extractable ower available from the wind is considerably more than present human ower use from all sources. Wind ower, as an alternative to fossil fuels, is abundant, renewable, widely spread, clean, and produces no greenhouse gas emissions during operation. Wind ower is the world‘s rapid growing source of energy.Currently, a huge amount of doubly-fed induction generators (DFIGs) in high-power wind turbine-generators (WTGs) are operational as distributed generators (DGs) units in microgrids. Recent grid codes require a WTG remains operational during transient and steady state unbalanced grid voltages.A voltage unbalance can steadily exist in a microgrid due to unequal impedance of distribution lines, nonlinear loads such as arc furnaces and unequal distributions of single-phase loads.A distributed intelligent residential load transfer scheme was proposed to dynamically reduce voltage unbalance along low voltage distribution feeders. However, due to using widely distributed and variable loads such as single-phase motors, and nonlinear loads in a microgrid, the voltage unbalance condition cannot be completely mitigated. On the other hand, even a small amount of voltage unbalance can cause notable current unbalance in a DFIG. This current unbalance causes torque pulsations and overheating of the machine windings which eventually reduce the lifetime of a DFIG-based WTG in a microgrid. Modeling and vector control of DFIG-based wind turbine under unbalanced conditions in microgrids are widely addressed in literature.The existing unbalanced vector control schemes for DGs conventionally use two pairs of individual controllers for the positive and negative sequence components of unbalanced currents.Tuning of these controllers due to the delays of the decomposing positive/negative sequences filters often requires complex algorithms in unbalanced vector control schemes.Alternative methods have been introduced which directly process the unbalanced rotor current without decomposition into positive/negative sequences. However, in these methods, the calculation of current references based on the ower pulsations also requires the positive and negative sequence components of the machine stator voltage, current, and flux. Direct ower control (DPC) methods have been also suggested for unbalanced voltage condition which relatively reduce the complexity of the control method compared to the vector control scheme.However, the DPC methods similar to the unbalanced vector control methods still need decomposition of positive/negative sequences and compensation for the filters delays. This project presents a control method for a DFIG connected to an unbalanced grid voltage, which uses the instantaneous real/reactive powers as the state variables. The proposed control approach offers a robust structure since its state variables are independent of the positive/negative sequences of the DFIG current components.The suggested control scheme also reduces the DFIG torque/power pulsations by using the real/reactive ower commands of the rotor-side converters in a DFIG wind energy system. Furthermore, at low wind speed and high unbalanced

Revised Manuscript Received on December 25, 2020.
* Correspondence Author

Hazara Begum*, Department of Electrical and Electronics Engineering, Surempalem, Peddapuram.
K. Sandhyarani, Department of Electrical and Electronics Engineering, Pragati Engineering College, Surampalem, Peddapuram.
Mrs. Ch V. V. Manga Lakshmi, Assistant Professor, Department of Electrical and Electronics Engneering, Pragati Engineering college surampalem.

grid voltage conditions, the excess capacity of grid-side converter can be used for partial compensation of unbalanced stator voltage. Two current/power limiting algorithms are also introduced for both rotor- and grid-side converters to avoid over rating of the converters. The performance of the proposed method under unbalanced grid voltage condition is investigated via time-domain simulation of a MW-scale DFIG wind turbine-generator study system in which a single-phase load is used to impose a steady voltage unbalance to the microgrid.This paper discussed the design of the Proposed system and performance characteristics of PI Controller Model in Section II, Modified Control Scheme in Section III. Simulation results & Analysis and conclusions are elaborated in Section IV and V respectively.

II. DESIGN OF PROPOSED SYSTEM

A.System configuration

The proposed system modelled on the Matlab / Simulink platform to improve the performance. In the proposed method, the rotor-side converter can be used for the mitigation of the torque and stator reactive ower pulsations. Also, the grid-side converter can be used for reduction of unbalanced stator voltage. In the proposed control method, the feedback loops are developed based on instantaneous real/reactive ower components which can be directly calculated in *abc* frame and used in any other reference frame. In the following, first the instantaneous ower model of a DFIG is explained and then the details of the proposed control strategy are explained within the followingsections

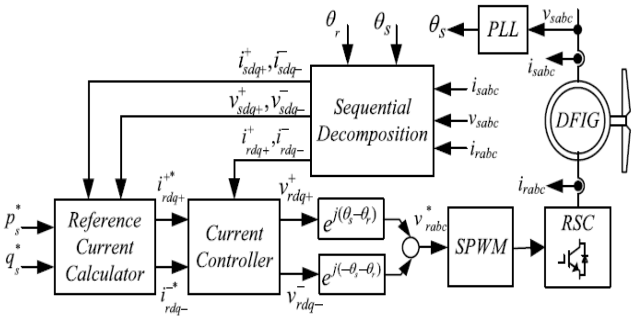

Fig. 1 conventional unbalanced vector control scheme for DFIG.

B.InstantaneousPowerModelofaDFIG

The model of the induction machine in terms of the stator real/reactive ower components, p_s and q_s,

$$\frac{d}{dt}\begin{bmatrix} p_s \\ q_s \\ \psi_{sd} \\ \psi_{sq} \\ \omega_r \end{bmatrix} = \begin{bmatrix} g_1 & -\omega_{sl} & -g_4 & -g_5 & 0 \\ \omega_{sl} & g_1 & -g_5 & g_4 & 0 \\ \frac{2r_s v_{sd}}{3|v_s|^2} & \frac{2r_s v_{sq}}{3|v_s|^2} & 0 & \omega_e & 0 \\ \frac{2r_s v_{sq}}{3|v_s|^2} & -\frac{2r_s v_{sd}}{3|v_s|^2} & -\omega_e & 0 & 0 \\ g_6 & g_7 & 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} p_s \\ q_s \\ \psi_{sd} \\ \psi_{sq} \\ \omega_r \end{bmatrix} + \begin{bmatrix} u_{rd} \\ u_{rq} \\ v_{sd} \\ v_{sq} \\ \frac{PT_m}{-J} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} \frac{dp_g}{dt} \\ \frac{dq_g}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{r_f}{L_f} & -\omega_e \\ \omega_e & -\frac{r_f}{L_f} \end{bmatrix}\begin{bmatrix} p_g \\ q_g \end{bmatrix} + \frac{1}{L_f}\begin{bmatrix} u_{gd} \\ u_{gq} \end{bmatrix} \tag{2}$$

Where

$$u_{gd} = \frac{3}{2}\left(|v_s{}^2| - \left(v_{gd}v_{sd} + v_{gq}v_{sq}\right)\right) \tag{3}$$

And

$$u_{gd} = \frac{3}{2}\left(v_{gq}v_{sd} - v_{gd}v_{sq}\right) \tag{4}$$

the dynamic model of the dc link is:

$$\frac{dv_{dc}}{dt} = \frac{i_{dc}}{C} = \frac{p_G - p_r}{CV_{dc}} \tag{5}$$

$\frac{dv_{dc}}{dt} = \frac{i_{dc}}{C}$where the real ower delivered to the rotor, p_r, is:

$$p_r = \frac{3}{2}\left(v_{rd}i_{rd} + v_{rq}i_{rq}\right) \tag{6}$$

Equations (1)-(6) summarize the model of a DFIG wind ower system including the machine and converters

III. CONTROL SCHEME

A. Compensation of Unbalanced Voltage Using GSC

The excess capacity of grid-side converter at low wind speed can be used for a partial compensation of unbalanced stator voltage. This can be achieved through the control of the real/reactive ower in GSC corresponding to the negative sequence of the grid voltage. This section develops the mathematical relationship between the ower pulsation and the negative sequence voltage which is required in the design procedure of the control system.

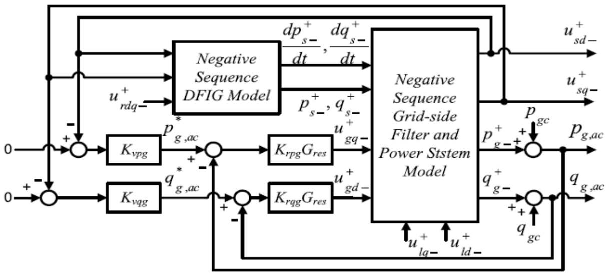

Fig. 2 GSC model for compensa tingthenega tivesequence of the grid voltage

The schematic diagram of the grid side converter model and DFIG in terms of ower components. In this model, ower pulsation references for GSC are used for adjusting the negative sequence grid voltage. In this control system, *GPg*, *GQg*and*Gdc*controllers are designed based on balanced model as elaborated in [21]. Then, extra control loops including *Kvdg*, *Kvqg*, *KrpgGres*and*KrqgGres* Are employed to control power pulsations of converter corresponding to pulsations of grid voltage at positive sequence reference frame. The resonant compensator (*Gres*) tuned at the double frequency of the grid which is implemented in the positive sequence reference frame. The notch filter *Gnf*is also used for suppressing the dc-link voltage double-frequency (2*ωe*) ripple. The transfer functions of resonant compensator and notch filter (*Gnf*) which are tuned at *ω*0 = 2*ωe* frequency are

$$G_{res} = \frac{\frac{\omega_o}{Q}s}{S^2 + \frac{\omega_0}{Q}s + \omega_0^2}$$

$$\mathrm{G_{res}} = \frac{\mathrm{S}^2 + \omega_0^2}{\mathrm{S}^2 + \frac{\omega_0}{\mathrm{Q}}\mathrm{s} + \omega_0^2}$$

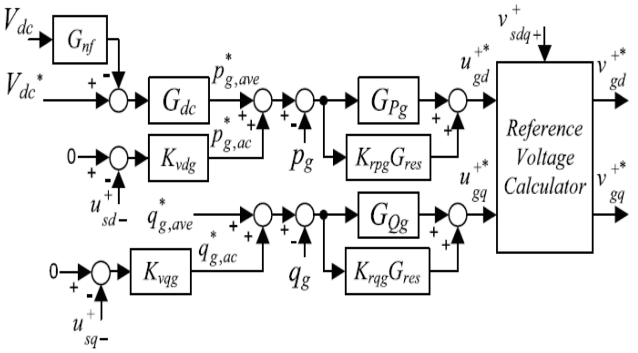

Fig.3proposed unbalanced controllers for the grid-side converter.

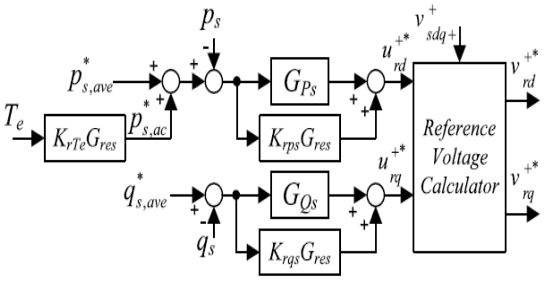

Fig. 4 proposed unbalanced controllers for the rotor-side converter

Where *Q* is the band-width of the filters. In the proposed control scheme, the instantaneous powers are controlled without decomposing the positive and negative sequences of currents. However, compensating of the unbalanced voltage requires the negative sequence ofstator voltage at positive sequence reference frame.

B. Mitigation ofTorque/ReactivePower Pulsations Using RSC

Although GSC to some extent can compensate the unbalanced grid voltage, the torque and power pulsations still exist due to 2*ωe* ripple which superimposed on the dc-link voltage. The torque pulsation in a generator increases stress on the rotating shaft of the DFIG which can cause shaft fatigue or other mechanical damages to a WTG. Thus, a control provision is required for the rotor-side converter to mitigate the torque/power pulsations of DFIG.Thus, the proposed control scheme herein is designed to compensate the torque and reactive power pulsations as shown in Fig. 5. This control scheme essentially consists of two controllers, *GPs* and *GQs*, which are designed for a balanced condition as discussed [21]. Then, extra feedback control loops including *KrpsGres*, *KrqsGres* and *KrTeGres* are added to compensate the double-frequency torque and reactive power pulsations without decomposing the positive and negative sequences of currents and voltages. The *Krps, Krqs* and*KrTe* are constant gains and *Gres* is a band pass filter tuned at double frequency as given in (23). The electric torque can be estimated by stator and rotor current components in the stationary reference frame as

$$T_e=3_pL_m/2(i_{sQ}i_{rD}\ \ -i_{sd}ir_Q)$$

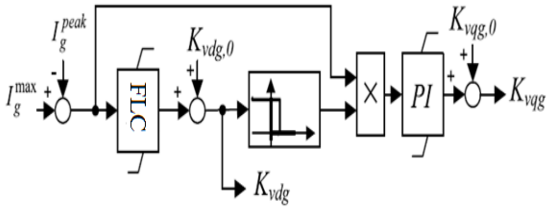

Fig. 5 Power limiter for the grid-side converter

The suggested control scheme in can be alternatively used for elimination of real and reactive power pulsations if $K_{rTe}$is set to zero

.

C. CURRENT/POWER LIMITING ALGORITM

Using power as a dynamic variable can cause over current of the power converter during transients and faults in a grid. This section presents an algorithm for limiting power references via sensing the converters currents.

Grid-Side Converter

In the control scheme for the grid-side converter (Fig. 4), the power capacity of the converter can be used for partially compensating the unbalanced stator voltage. However, it is necessary that the converter maintain the dc-link voltage via control of average real power and supplying the rotor real power has the highest priority. Thus, the maximum and mini-mum limits of average real power will be set to the maximum and minimum complex power.

Based on

$p^*_{g.ac}=K_{vdg}\ u^+_{ds}-q_{g,ac}=K_{vqs}\ u^+_{qs}$

, presents a method for limiting the power pulsation references via adjusting *Kvdg* and *Kvqg*. In this method *Kvdg* and *Kvqg*are initially set to pre-adjusted quantities *Kvdg*0 and *Kvqg*0. The unbalanced grid voltage is compensated using these fixed gains until the peak current of converter (*Ipeakg*) passes its maximum limit. Then, in the first step, *Kvqg*is decreased to reduce the *q∗ g,ac*and if *q∗ g,ac* reaches zero and still *Ipeak g* is beyond its limit, then *Kvdg*is decreased to reduce *p∗ g,ac*.Therefore, the unbalanced grid voltage compensation can be partially or completely deactivated during the over current of the grid-side converter.

Rotor-Side Converter

Under a normal operating condition, the reference for the stator real power is adjusted to capture the maximum wind energy.

Retrieval Number: 100.1/ijeat.B20731210220
DOI:10.35940/ijeat.B2073.1210220
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication

This reference can be obtained via any maximum power point tracking (MPPT) algorithm [24]. The stator reactive power reference is also adjusted to satisfy the power factor requirements at the grid. Therefore, the maximum currents of the rotor and stator windings determine the upper limits of the generator real and reactive powers. Similar to the grid-side converter, the limits for the generator real/reactive can be obtained.

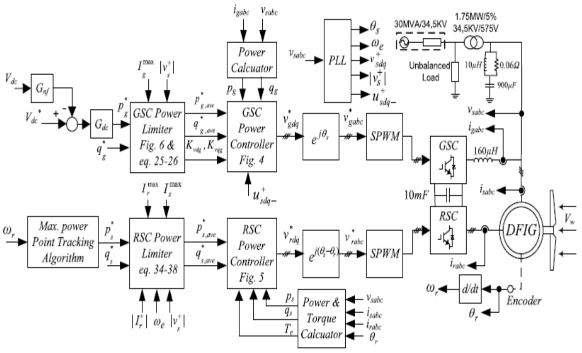

Fig.6 Schematic diagram of the study system.

Thus, the limits for the stator power components can be expressed as:

$$p_s^{max2} = -p_s^{min2} = \frac{\omega_e s_r^{max}}{\omega sl} = \frac{3|v_s^+|I_r^{max}}{2N_{sr}}$$

$$q_s^{max2} = -\frac{3|v_s^+|^2}{2L_s\omega_e} - \frac{3}{2}L_r'\omega_e|i_r^+|^2 + \sqrt{\left(\frac{3|v_s^+|I_r^{max}}{2N_{sr}}\right)^2 - p_s^2},$$

$$q_s^{min2} = -\frac{3|v_s^+|^2}{2L_s\omega_e} - \frac{3}{2}L_r'\omega_e|i_r^+|^2 - \sqrt{\left(\frac{3|v_s^+|I_r^{max}}{2N_{sr}}\right)^2 - p_s^2}.$$

and the real/reactive power limits for the rotor-side converter can be defined as:

$$p_s^{min}=\max\left(p_s^{min1},p_s^{min2}\right),p_s^{max} = \min(p_s^{max1},p_s^{max2})$$

$$q_s^{min}=\max\left(q_s^{min1},q_s^{min2}\right),q_s^{max} = \min(q_s^{max1},q_s^{max2})$$

By using these limits during transients conditions, the capacity of RSC is partially used for injecting reactive power to the grid while the capacity of GSC is used for maintaining the dc-link voltage and compensation of unbalanced voltage.

IV. SIMULATION AND RESULTS

MATLAB/SIMULINK comes about are introduced in this segment for approving unfaltering state and dynamic exhibitions of this proposed DFIG with coordinated dynamic channel capacities. In this area, the working of this proposed GSC is displayed as a dynamic channel notwithstanding when the breeze turbine is in shutdown condition. The power that is coming into the PCC through GSC is considered as positive in this paper.In this area, the working of this proposed GSC is exhibited as a dynamic channel notwithstanding when the breeze turbine is in shutdown condition. The power that is coming into the PCC through GSC is considered as positive in this paper. The reproduced execution of this proposed DFIG is displayed at a 10.6-m/s wind speed. As the proposed DFIG is working at MPPT, the reference speed of the DFIG is chosen as 1750 rpm. The heap streams are seen to be nonlinear in nature. The GSC. is providing required sounds streams to the heap for making network ebbs and flows (igabc) and stator ebbs and flows (isabc) adjusted and sinusoidal. At above synchronous speed, the power stream is from the GSC to PCC, so the GSC control is appeared as positive. Add up to controldelivered by the DFIG is the whole of stator control (Ps) and GSC control (Pgsc). Subsequent to sustaining energy to the heap (Pl), the rest of the power is nourished to the network (Pg).

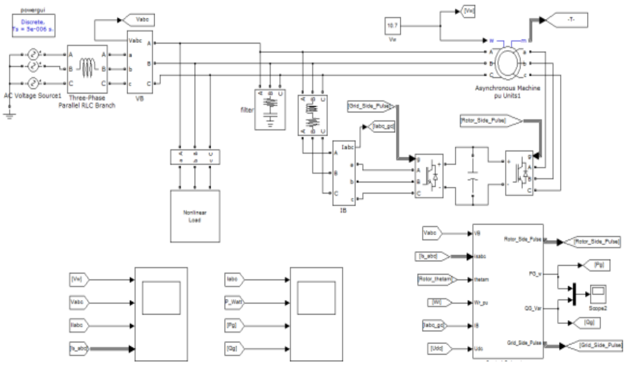

Fig. 7 MATLAB SIMULINK Model of the Proposed DFIG

A. Simulation waveforms

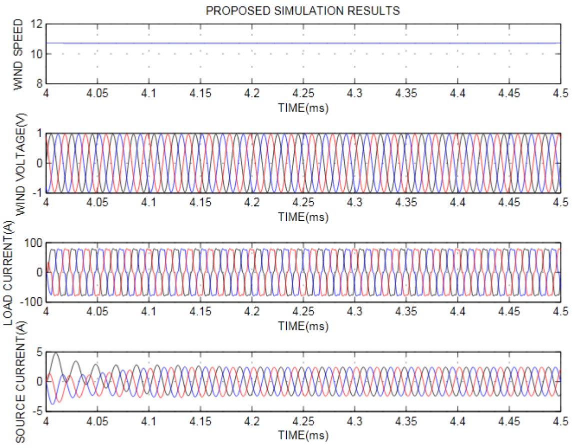

Fig. 8 The DFIG performance under unbalanced voltage using balanced controller: constant wind speed 10.6m/s, wind voltage, load current and source current.

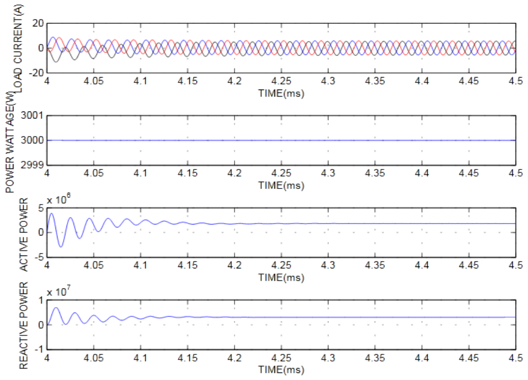

Fig.9 Simulated performance of the proposed DFIG-based WECS at fixed wind speed of 10.6 m/s.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication

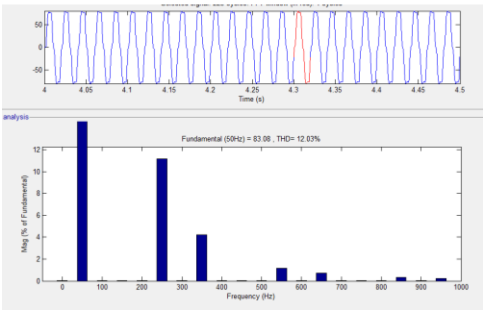

Fig.10 Total Harmonic Distortion of Load current (Ilabc)in %

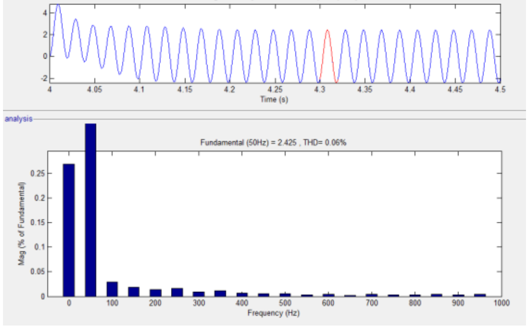

Fig. 11 Total Harmonic Distortion of Source current (Isabc) in %

V. CONCLUSION

An unbalanced control scheme for a DFIG wind turbine-generator has been presented in this paper which does not require the sequential decomposition of the DFIG stator/rotor currents and is less sensitive to the system parameters. This control scheme mitigates the stator reactive power and torque pulsations which obviously appears in any balanced con-trol scheme under an unbalanced grid voltage condition. The control method uses the grid-side converter to partially com-pensate the unbalance stator voltage when the wind speed is low and turbine works below nominal power. Two cur-rent/power limiting algorithms are alsointroduced for both rotor- and grid-side converters to avoid over rating of the converters. It has been shown that proposed control approach based on its simple and robust structure can offer a promis-ing solution for DFIG control under unbalanced grid voltage conditions for non-linear loads.

REFERENCES

1. M. Mohseni and S. M. Islam, “Review of international grid codes for wind power integration: Diversity, technology and a case for global standard,” *Renew. Sustain. Energy Rev.*, vol. 16, no. 6, pp. 3876–3890, 2012.
2. C. Jauch, J. Matevosyan, T. Ackermann, and S. Bolik, “International comparison of requirements for connection of wind turbines to power systems,” *Wind Energy*, vol. 8, no. 3, pp. 295–306, 2005.
3. F. Shahnia, P. J. Wolfs, and A. Ghosh, “Voltage unbalance reduc-tion in low voltage feeders by dynamic switching of residential cus-tomers among three phases,” *IEEE Trans. Smart Grid*, vol. 5, no. 3,pp. 1318–1327, May 2014.
4. R. Piwko*et al.*, “Integrating large wind farms into weak power grids with long transmission lines,” in *Proc. CES/IEEE 5th Int. Power Electron.Motion Control Conf. (IPEMC)*, vol. 2. Dalian, China, 2006, pp. 1–7.
5. K. Lee, T. M. Jahns, W. E. Berkopec, and T. A. Lipo, “Closed-form analysis of adjustable-speed drive performance under input-voltage unbalance and sag conditions,” *IEEE Trans. Ind. Appl.*, vol. 42, no. 3,pp. 733–741, May/Jun. 2006.
6. E. Nasr-Azadani, C. A. Cañizares, D. E. Olivares, and K. Bhattacharya, “Stability analysis of unbalanced distribution systems with synchronous machine and DFIG based distributed generators,” *IEEE Trans. SmartGrid*, vol. 5, no. 5, pp. 2326–2338, Sep. 2014.
7. H. Xu, J. Hu, and Y. He, “Integrated modeling and enhanced control of DFIG under unbalanced and distorted grid voltage conditions,” *IEEETrans. Energy Convers.*, vol. 27, no. 3, pp. 725–736, Sep. 2012.
8. [8] J. Hu and Y. He, “DFIG wind generation systems operating with limited converter rating considered under unbalanced network conditions—Analysis and control design,” *Renew. Energy*, vol. 36, no. 2,pp. 829–847, 2011.
9. *Y. Yan, M. Wang, Z.-F. Song, and C.-L. Xia, “Proportional-resonant control of doubly-fed induction generator wind turbines for low-voltage ride-through*
10. C. Liu, F. Blaabjerg, W. Chen, and D. Xu, “Stator current harmonic control with resonant controller for doubly fed induction generator,” *IEEE Trans. Power Electron.*, vol. 27, no. 7, pp. 3207–3220, Jul. 2012.
11. P. Zhou, Y. He, and D. Sun, “Improved direct power control of a DFIG-based wind turbine during network unbalance,” *IEEE Trans.Power Electron.*, vol. 24, no. 11, pp. 2465–2474, Nov. 2009.
12. Y. Zhou, P. Bauer, J. A. Ferreira, and J. Pierik, “Operation of grid-connected DFIG under unbalanced grid voltage condition,” *IEEE Trans.Energy Convers.*, vol. 24, no. 1, pp. 240–246, Mar. 2009.
13. L. Xu and Y. Wang, “Dynamic modeling and control of DFIG-based wind turbines under unbalanced network conditions,” *IEEE Trans. PowerSyst.*, vol. 22, no. 1, pp. 314–323, Feb. 2007.
14. M. Savaghebi, A. Jalilian, J. C. Vasquez, and J. M. Guerrero, “Secondary control scheme for voltage unbalance compensation in an islanded droop-controlled microgrid,” *IEEE Trans. Smart Grid*, vol. 3, no. 2,pp. 797–806, Jun. 2012.
15. M. Hamzeh, H. Karimi, and H. Mokhtari, “Harmonic and negative-sequence current control in an islanded multi-bus MV microgrid,” *IEEETrans. Smart Grid*, vol. 5, no. 1, pp. 167–176, Jan. 2014.
16. L. Xu, “Enhanced control and operation of DFIG-based wind farms during network unbalance,” *IEEE Trans. Energy Convers.*, vol. 23, no. 4,pp. 1073–1081, Dec. 2008.
17. V.-T. Phan and H.-H. Lee, “Performance enhancement of stand-alone DFIG systems with control of rotor and load side converters using res-onant controllers,” *IEEE Trans. Ind. Appl.*, vol. 48, no. 1, pp. 199–210, Jan./Feb. 2012.
18. G. Abad, M. A. Rodriguez, G. Iwanski, and J. Poza, “Direct power control of doubly-fed-induction-generator-based wind turbines under unbalanced grid voltage,” *IEEE Trans. Power Electron.*, vol. 25, no. 2,pp. 442–452, Feb. 2010.

AUTHORS PROFILE

Hazara Begum, graduated from Pragati Engineering college, Surempalem, peddapuram. she is pursuing M.tech in the Department of Electrical and Electronics Engineering, Surempalem, Peddapuram. His research areas include Power Electronics Converters, drives, Renewable Energy Systems and storage systems.

K. Sandhyarani, Post Graduated from Newton's Institute of Engineering college,Macherla, Guntur. She is presently working as Assistant Professor in the Department of Electrical and Electronics Engineering, Pragati Engineering College, Surampalem, Peddapuram. She had published 1 research paper in International journals. Her research area is Power Electronics. She has an IAENGmembership

Mrs. Ch V. V. Manga Lakshmi, Post graduated from Pragati Engineering college, Surampalem, Peddapuram. She is presently working as Assistant Professor in the Department of Electrical and Electronics Engneering, Pragati Engineering college surampalem. she had published 6 research papers in International Journals. Her areas of interest are Power Electronics, control systems and Electrical Machines .