STATCOM with Novel control strategy for Power Quality Improvement in Grid connected Wind energy conversion system

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Abstract: This paper addresses a novel control strategy dependent static synchronous compensator (STATCOM) to intensify power quality for efficacious power transfer and frequency control of a grid-pertinent wind farms. This proposed system consist of two wind power generating systems in which one generator replicated by an commensurate doubly-fed asynchronous generator operated by an tantamount wind turbine while other generator is simulated by an squirrel-cage rotor asynchronous generator driven by wind turbine. The dynamic changes in load will create dearth for active and reactive power at load bus resulting in variations in frequency and magnitude load voltage. This quandary can be elucidated by amalgamating the modifiable reactive power fount (STATCOM) at load bus so that voltage can be regulated, simultaneously the reactive power strain on wind farm is reduced so that active power injected in to grid increases which stabilizes the grid frequency. Three conditions are designed (I) autonomous mode, (II) grid- amalgamated mode and (III) grid-amalgamated mode with STATCOM, are examined to juxtapose their dynamic and transitory behavior. From Results it can be observed that case-III best contended the dynamic recompense demand out of all conditions.

Key–Words: Static synchronous compensator, power quality improvement, control strategy and MATLAB

1 Introduction

The electrical supply from conventional sources are not able to fulfill the load demand and thus increasing the power quality problems and environmental pollution [1,2].Due to the usage of intermittent renewable energy and connecting to grid may result in certain problems like-Issues of synchronization, Power quality issues, Voltage quality issues, Bidirectional power flow, Power complexity issues, Additional compensation circuit is required. The drastic increase in the power demand because of heavy industries, domestic and agriculture needs. The energy obtained from wind farm is a atmospheric-receptive type of empirical system because of non-appearance of discharge deleterious to the atmosphere. The maximum customary type of Megawatt-range wind farms deploys asynchronous generators as they are comparatively less cost, stiff and crave less maintenance. The dynamics of wind velocity will impact on power quality linked with the requirement for an excitation current make the voltage regulation strenuous, particularly when the IG is integrated to a fragile ac system [3]-[6]

1.1 Literature Survey

In past twenty years, in the place of conventional resources using renewable energy resources the non conventional and distributed energy resources are solution in later the power demand and overcome the power quality problems. Regardless of their discontinuous attitude and intrinsic defaults, Multiple wind RES is utilized to fulfill the load demands with good reliability and without power interrupts. The intermittent nature of these sources will affect critical stability between RES and connected loads. As a result variations in system bus voltage, frequency, power system oscillations and generation of unnecessary reactive power is caused which effecting the system power quality and stability [7]. stand-alone Wind farms seems to comfortable for stand-alone low power demand application. Philip et al [8] explained problems with solar integration and suggested that sum of Decentralized generation and energy storage systems may increase the trait of power. Power quality issues are reducing by using power electronic based FACTS devices [9].Several devices are used investigated providing expected results. In order to suppress unwanted internal swings in power systems various devices like SVC,STATCOM,PSS were examined and collated [10].The integrated SVC and STATCOM system based on effective voltage control strategy on a linked transmission system with asynchronous generators in wind farm was examined[11]. The impertinent postulation of an independent wind driven asynchronous generator [IG] was represented by prakash et al [12] though different strategies and regulation techniques are discussed in the research, by using typical controllers faced some power quality problems. In this situations, FACTS devices are better for improvement of power quality [13]. Compare to other FACTS devices STATCOM and SVC are better for reactive power compensation and voltage profile support [14]. SVC is a good FACTS device for enhance power quality issues in HRES [15, 16] based reactive power control. STATCOM have better performance compare to SVC [17,18]. The independent current control of STATCOM based on reference frame acquired appreciable recognition in [19,20]. The authors conferred a noteworthy forward by making the d-axis inevitably be coordinate with the source voltage, where active and reactive power were dappled. The mismatch in the active ad reactive power and the DC link voltage drop is compensated with the help of feed forwarded reactive current control loop [21]. More information may be found in [22-31] about the power quality, reactive power compensation and control strategy for FACTs devices.

1.2 Organization of the article

The rest of this work includes the comprehensive modeling, simulation and widespread performance scrutiny of Wind farm energy system integrated to grid through power converter interface. To emulate pragmatic conditions these intermittent nature of wind farm is connected to highly varying ac loads. This dynamical nature of mixed loads will definitely create the dearth of reactive power eventually voltage drop occurs at load bus. Under these conditions, STATCOM is anticipated to be a exclusive device. It is verified to enhance the voltage regulation in autonomous systems as preferred by several authors. This complete case study is modeled and simulated in MATLAB/Simulink 2018(a). The Results will evaluate the pursuance and substantiate the practicability of the grid- amalgamated wind farm system among solitary systems and to validate the appropriateness of STATCOM in the enhancement of the voltage portrait of load bus.

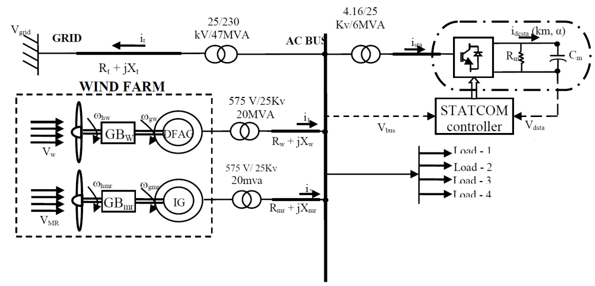

Figure 1: Diagram of Distribution system

2 System Description

Fig.1 depicts the structure of generation with STATCOM interconnected to distribution grid. This wind farm is integration two wind turbine-generation systems i.e. (i) Wind turbine with Double fed induction generation system(DFAG) [10MW] (ii) Wind turbines [3x3mw] coupled with induction generators for electrical power production. Power electronic devices as very useful to interface, integrate and inject power to grid. In wind for MPPT combined with pitch angle controller is employed to Overcome any damages above the maximum speeds by governing the pitch angle. The Wind turbine with Double fed induction generation system(DFAG),Wind turbines coupled with induction generators, The AC loads, wind generation and STATCOM are integrated at the point of common coupling ad it is fed with the grid through the step-up transformer. The mathematical model ca e analyzed in the following way. A STATCOM is combined with normal PI control observed allowed values of load bus voltage and current. The triggering signals are produced correspondingly, which govern STATCOM reactive power regarding to discrepancy. The different AC loads are taken to analyze the system.

3 Wind energy conversion system

3.1 Wind Turbine Model

Usually wind farm have various positioned turbines to fulfill a single objective to gather the mechanical energy. Thus obtained mechanical energy transformed into electrical energy with the help electrical generators. The mechanical output energy generated by turbine mainly depends on air density, radius of blade, wind velocity and power coefficient. This power coefficient depends on tip speed ratio and pitch angle. The expression for mechanical power is given as

$$P_m = \frac{1}{2}\rho\pi r^2 V_w^3 C_p \tag{1}$$

3.2 Turbine control by Pitch Angle

The turbine blade pitch angle is controlled by limiting the output power of generator .Basically induction generator speed is slightly higher then the synchronous speed but the speed changes commonly. So that the WTAG is treated to be attached speed wind generator. By using PT controller to control the pitch angle and it is maintained at zero degree, restraint electrical power to the exhibited mechanical power when it is more than its ostensible value then the pitch angle also escalates with the help of PI controller the control system pitch angle control shown in Fig.2

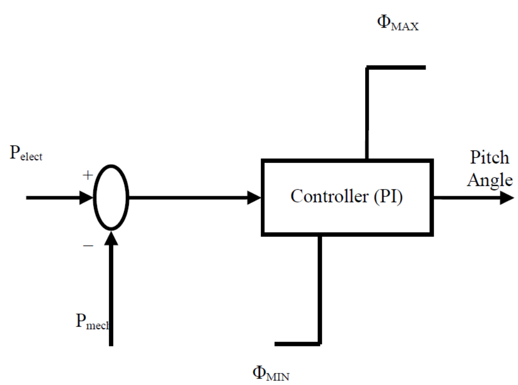

Figure 2: PI controller the control system pitch angle control

3.3 Mass Spring Damper system and Induction Generator

Fig 3 Schematic diagram of the suggested DFIG, the main effect of this model gear box between the DFAG and WT has been included. The per unit values of current and voltage equations of an IG [22]-[23] and it can be used for the electrical equipments of the WDFAG.

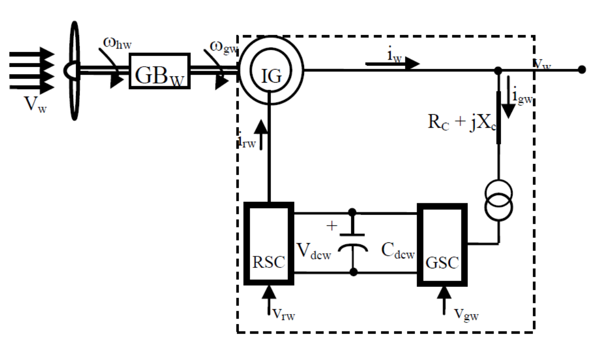

Figure 3: Schematic diagram of DFAG

The DFAG and the wind turbine gearbox equivalent circuit is consider in this model. The voltage and current of proposed system is analyzed with the p.u. system [24]-[26] and [27]-[33]. The schematic diagram of wind DFAG is shown in fig.3 low voltage side of the 575/25kv step up transformer is converted with starter winding of DFAG and rotor is connected with another side through rotor power converter grid side converter and connection line.

4 STATCOM

STATCOM is connected parallel to the load. It can be used for eliminating the voltage cohesion problems, enhance the voltage regulation and reactive power compensation [15].By using VSC the generation or absorbing of reactive power depends on our requirements, below equations shows the active and reactive powers with two different voltage sources VT and VS. The Schematic diagram of STATCOM is shown in Fig 04.

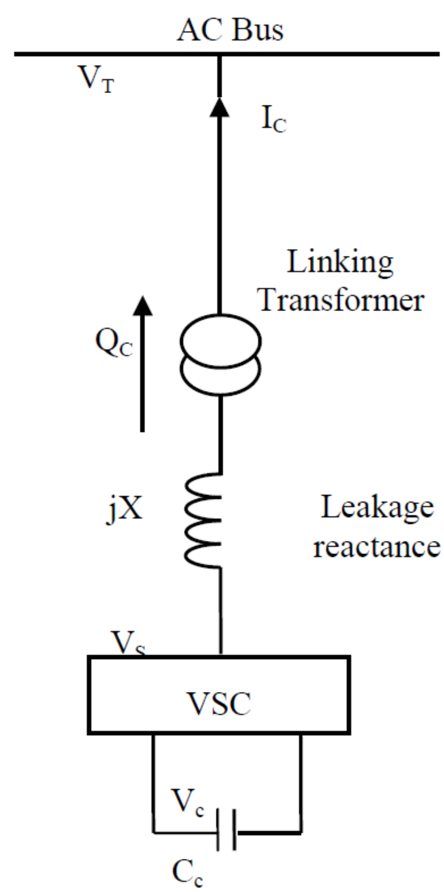

Figure 4: The Schematic diagram of STATCOM

Where,

V_T AC bus voltage to be maintained stiff
V_S Output Voltage of VSC
X Transformer Reactance
δ Angle between V_T and V_S Under Normal condition, V_T and V_S are in phase and δ is equal to zero degrees under such circumstances the reactive power will be exchanged between them. Two circumstances may get; V_T is greater than VS or vice–versa. Therefore, the quantity of reactive power consumed or injected is calculated.

5 Control stategy

This control structure principle is to interject the currents into the grid using "dq control theory." The primary intention of control plan is to generate triggering signals to the VSC used in STATCOM shown in Fig.5. The control plan requires the parameters such as grid voltages, currents, DC link voltage. Phased locked loop is used for grid synchronization. Q-axis reference voltage is obtained by comparing the measured three phase grid voltages with reference ac voltages .The measured value of dc link capacitor voltage is collated with command dc voltage and the error passed through PI controller to generate reference d-axis current .The generated command dq-axis currents is then compared original dq-axis currents to generate reference voltages for PWM modulator to generate switching signals for STATCOM to inject required reactive current.

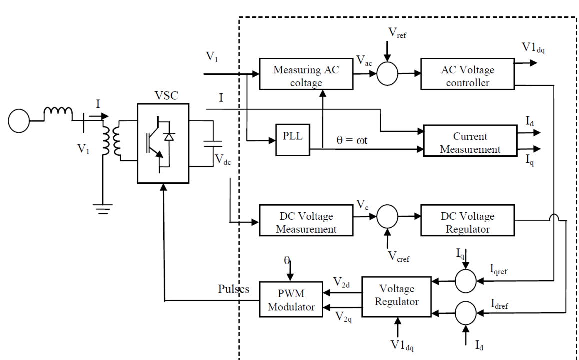

Figure 5: Control strategy for STATCOM

6 Simulation results and Discussion

The proposed control strategy for power quality improvement is developed in MATLAB (2017b) version.

6.1 Wind speed

The generator-1 consider as the base generation. Generatore-2 is considered to create the dynamic variations in the generation. The wind speed of the generator 2 shows the variations in wind speed . It is displayed in Fig 06.

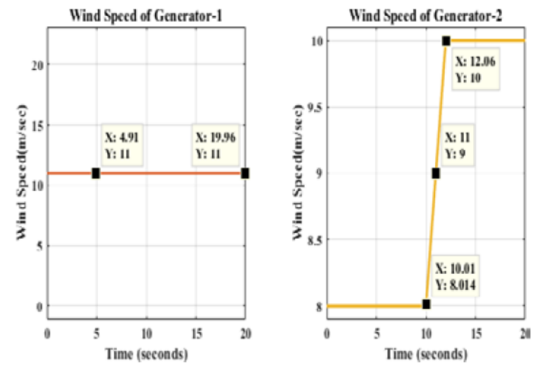

Figure 6: Wind speed profile of Generator 1 and 2

6.2 Variation in load voltage

Sudden switching of the inductive load and the voltage variation is shown in Fig 07. In the first case, the voltage drop variations is more due to switching of R-L load as plotted in the case-1 figure during the t=3sec to 9sec. However the reactive power obtained from suggested system is inadequate as a result the voltage drop occurs at load bus. In the case-II, voltage portrait is revised up to some extent but due to the lack of the grid to support such a high inductive load along with large resistive loads, the voltage profile still needs to be improved further. In case-III, the STATCOM is deployed. The results in the case-III shows the better voltage profile improvement compared to case-I and case II respectively.

Load voltages in different cases is shown in Fig 09. Dynamic switching of inductive load t=3sec to t=9sec is shown. During this period in case three shows that the voltage profile improved with the STATCOM.

According to dynamic switching of the four loads reactive performance is shown in the figure. The load1, 2 are restive loads and the load3 is R-L load and Load 4 is the Inductive load. According to dynamic switching of the load performance is shown in the figure

According to dynamic switching of the four loads reactive performance is shown in the figure. The load 1 and load 2 reactive power is zero hence the loads are resistive loads.

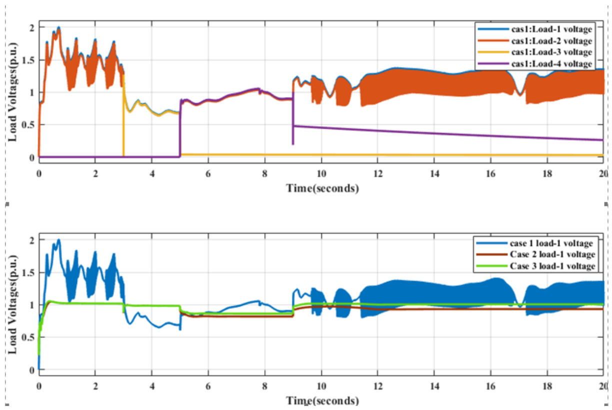

Figure 7: a) Case study-1:Load voltages (b) Case study 1:Load-1 voltages

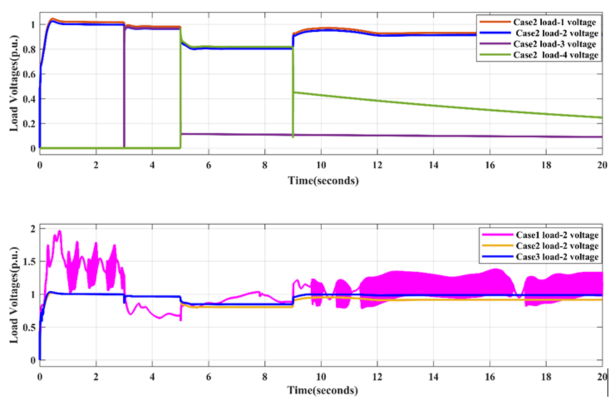

Figure 8: (c)Case study-2:Load voltages(d) Case study-2:Load-2 voltages

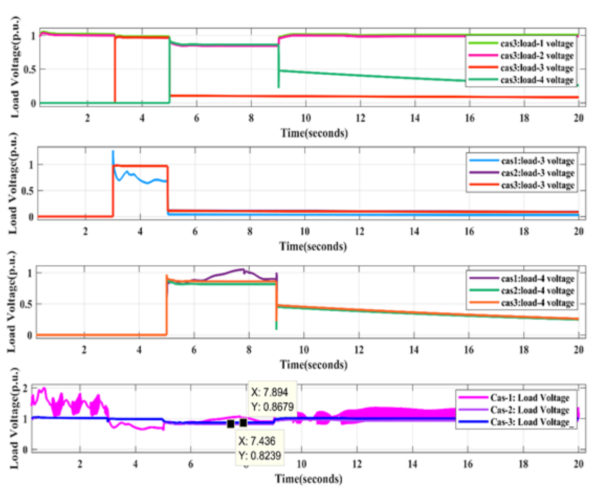

Figure 9: (a) Case study-3:Load voltages (b) Case study-3:Load-3 voltages

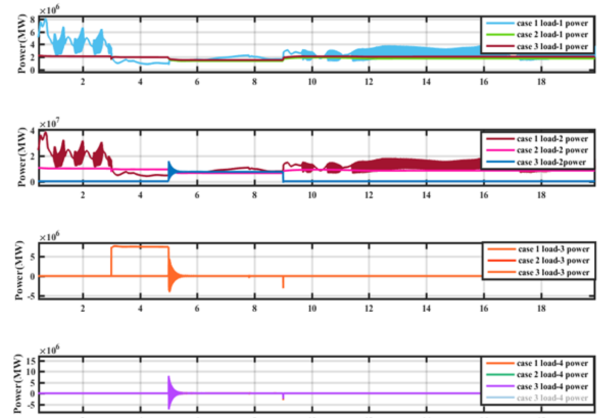

Figure 10: Load true power for loading-1,2,3 and 4

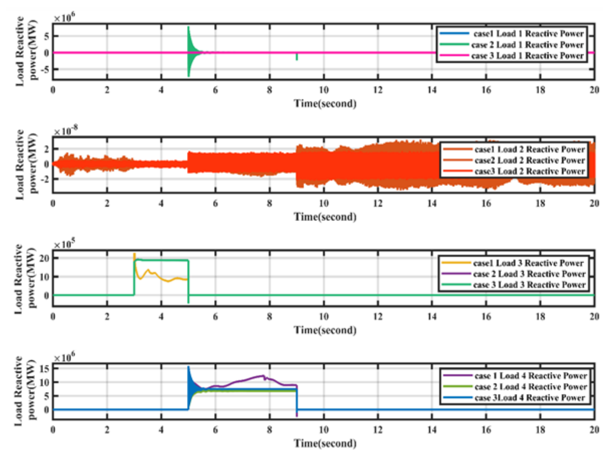

Figure 11: load reactive power for load-1,2,3 and 4

6.3 Variation in reactive power of STATCOM

In case one and case-2 STATCOM is not integrated with the system. The reactive power exchange is shown in the figure. Initially the reactive power support is more due to insufficient sharing power from wind generation. It maintain the necessary active power flow. At T=4 sec to 12sec the change in the inductive load require the necessary reactive power and it is it is supported with STATCOM as shown in the figure.

6.4 Variation in Grid and Reactive Active power

Grid power in isolated case-1 et power delivery is zero (Pnet, Qnet)=0 Case-2 and 3:Grid integrated mode active power and reactive power are shown in the figure.

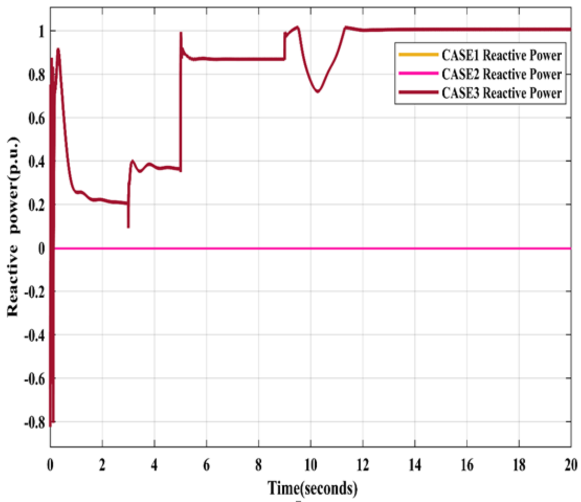

Figure 12: Load reactive power for case I,II and III

Active and reactive power delivery in the case-2 is less then the case three. Incase-3 the reactive power support supported with the STATCOM. The burden on the grid is reduced.

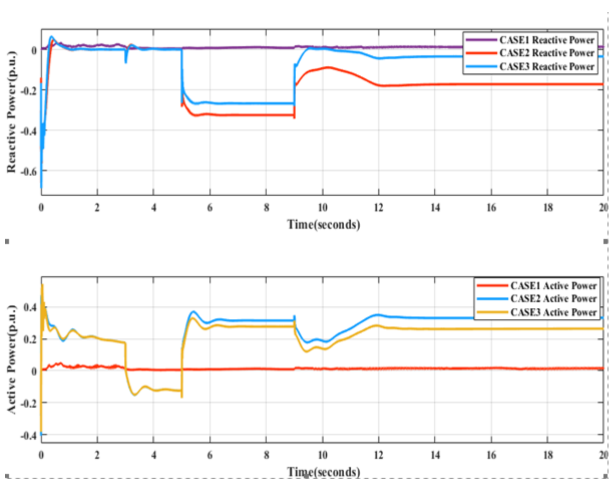

Figure 13: Grid active and reactive power for case I,II and III

6.5 Switching of Loads

STATCOM is a reactive power compensating device and supports the maintain voltage profile. However, among the both devices for the same rating the STATCOM perform the better performance. The intermittent renewable wind firm and the dynamic switching of load leads to create the voltage instability and reactive power mismatch. This effect can be reduced with

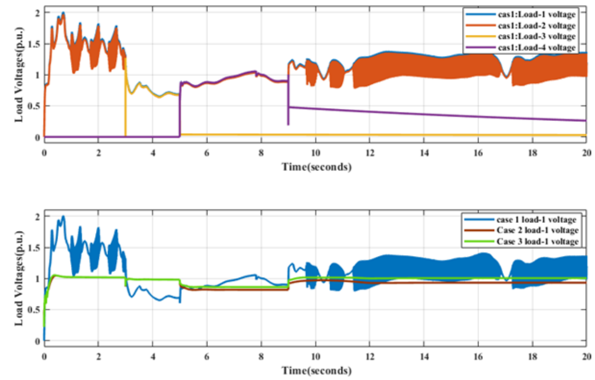

Figure 14: load switching

the use of STATCOM. The grid integrated wind generation with STATCOM under dynamic load performance is presented, which not yet to be done. Hence, there is need to perform under dynamic source and load condition. The dynamic switching of the RL, and inductive load has been presented in different interval at t=3 to 5sec and 5 to 9sec respectively.

7 Conclusion

This paper has conferred the power quality revampment in wind generation interconnected grid arrangement by regulating the voltage and frequency at load bus .To evaluate the voltage, frequency regulation and reliability three different case studies was simulated with four different dynamically varying loads. Assessable investigation is also lugged out for transitory responses acquired for each case, which is clearly showing the effectiveness of STATCOM in regulating the voltage at load bus. Among all the cases case-III found to be more effective because the STATCOM hold the potential to maintain the voltage at the load bus by regulating reactive power. The added feature of this system is by compensating reactive power with the aid of STATCOM the reactive power strain on wind farm is reduced which indirectly regulating the grid frequency.

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References:

[1] Khare V, Nema S, Baredar P. Solar-wind hybrid renewable energy system: a review. Renewable Sustainable Energy Rev 2016;58:23–33.

[2] Jamil B, Siddiqui AT, Akhtar N. Estimation of solar radiation and optimum tilt angles for south-facing surfaces in Humid Subtropical Climatic Region of India. Eng Sci Technol an Int J 2016;19:1826–35.

[3] W. L. Chen, Y.-H. Lin, H.-S. Gau, and C.-H. Yu, "STATCOM controls for a self-excited induction generator feeding random load," IEEE Trans. Power Del., vol. 23, no. 4, pp. 2207 2215, 2008.

[4] W. L. Chen and Y. Y. Hsu, "Controller design for an induction generator driven by a variable-speed wind turbine," IEEE Trans. Energy Convers., vol. 21, no. 3, pp. 625–635, 2006.

[5] V. Akhmatov, "Analysis of Dynamic Behaviour of Electric Power Systems with Large Amount of Wind Power," Ph.D. dissertation, Technical Univ. Denmark, Kgs. Lyngby, 2003.

[6] W. Freitas, A. Morelato, W. Xu, and F. Sato, "Impacts of AC generators and DSTATCOM devices on the dynamic performance of distribution systems," IEEE Trans. Power Del., vol. 20, no. 2, pp. 1493–1501, 2005.

[7] IEA. Global energy demand rose by 2.3 % in 2018, its fastest pace in the last decade. International Energy Agency (IEA),

[8] Philip J, Jain C, Kant K, Singh B, Mishra S, Chandra A, et al. Control and implementation of a autonomous solar photovoltaic hybrid system. IEEE Trans Ind Appl 2016;52:3472–9.

[9] Hingorani NG, Gyugyi L. Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. New York, NY: USA Wiley-IEEE Press; 2000. p. 1–6.

[10] N. Mithulananthan, C. A. Canizares, J. Reeve, and G. J. Rogers, "Comparison of PSS, SVC, and STATCOM controllers for damping power system oscillations," IEEE Trans. Power Syst., vol. 18, no. 2, pp. 786–792, May 2003.

[11] R. Griinbanm, P. Halvarsson, D. Larsson, and P. R. Jones, "Conditioning of power grids serving offshore wind farms based on asynchronous generator," in Proc. Conf. Power Electronics, Machine and Drives, Mar./Apr. 2004, vol. 1, pp. 34–39.

[12] Prakash SL, Arutchelvi M, Jesudaiyan AS. Autonomous PV-array excited winddriven induction generator for off-grid application in India. IEEE J Emerg Sel Top Power Electron

[13] Pereira RMM, Ferreira CMM, Barbosa FM. Comparative study of STATCOM and SVC performance on dynamic voltage collapse of an electric power system with wind generation. IEEE Lat Am Trans 2014;12:138–45.

[14] Lijie D, Yang L, Yiqun M. Comparison of high capacity SVC and STATCOM in real Bpower grid. 2010 Int. Conf. Intell. Comput. Technol. Autom. 2010. p. 993–7.

[15] Kassem AM, Abdelaziz AY. Reactive power control for voltage stability of autonomous hybrid wind–diesel power system based on functional model predictive control. IET Renewable Power Gener 2014;8:887–99.

[16] Mi Y, Ma C, Fu Y, Wang C, Wang P, Loh PC. The SVC additional adaptive voltage controller of isolated wind-diesel power system based on double sliding-mode optimal strategy. IEEE Trans Sustainable Energy 2018;9:24–34.

[17] Mithulananthan N, Canizares CA, Reeve J, Rogers GJ. Comparison of PSS, SVC, and STATCOM controllers for damping power system oscillations. IEEE Trans Power Syst 2003;18:786–92.

[18] Tayyebifar T, Shaker M, Aghababaie M. Performance comparison of STATCOM versus SVC to improve reactive power control in wind power based DFAG under short circuit fault. 2014 Ninth Int Conf. Ecol. Veh. Renewable Energies 2014. p. 1–7.

[19] C. D. Schauder, M. Gernhardt, E. Stacey, T. Lemak, L. Gyugyi, T. W. Cease, and A. Edris, "Development of static condenser for voltage control of transmission systems," IEEE Trans. Power Del., vol. 10, no. 3, pp. 1486–1496, 2005.

[20] C. D. Schauder and H. Mehta, "Vector analysis and control of advanced static VAR compensators," Proc. Inst. Elect. Eng., vol. 140, no. 4, pt. C, pp. 299–306, 2006.

[21] J. Sun, S. Beineke, and H. Grotstollen, "Optimal PWM based on realtime solution of harmonic elimination equations," IEEE Trans. Power Electron., vol. 11, no. 4, pp. 612–621, 2006.

[22] Modeling New Forms of Generation and Storage, Jun. 2000, CIGRE, TF.01.10, 5th draft.

[23] P. C. Krause, Analysis of Electric Machinery. New York: McGraw- Hill, 1987.

[24] D. J. Trudnowski, A. Gentile, J. M. Khan, and E. M. Petritz, "Fixedspeed wind-generator and wind-park modeling for transitory stability Nstudies," IEEE Trans. Power Syst., vol. 19, no. 4, pp. 1911–1917, Nov. 2004.

[25] S. M. Muyeen, M. H. Ali, R. Takahashi, T. Murata, J. Tamura, Y. Tomaki, A. Sakahara, and E. Sasano, "Transitory stability analysis of wind generator system with the consideration of multi-mass shaft model," in Proc. Int. Conf. Power Electronics and Drives Systems, Jan. 16–18, 2006, vol. 1, pp. 511–516.

[26] P. Cartwright, L. Holdsworth, J. B. Ekanayake, and N. Jenkins, "Coordinated voltage control strategy for a doubly-fed induction generator (DFAG)-based wind farm," Proc. Inst. Elect. Eng., Gen., Transm., Distrib., vol. 151, no. 4, pp. 495–502, Jul. 2004.

[27] Jamil E, Hameed S, Jamil B (2019) Power quality improvement of distribution system with photovoltaic and permanent magnet synchronous generator based renewable energy farm using static synchronous compensator. Sustain Energy Technol Assess 35:98–116

[28] Noureldeen O, Ibrahim AM (2018) Modeling, implementation and performance analysis of a grid-connected photovoltaic/wind hybrid power system. In: International conference on innovative trends in computer engineering (ITCE), pp 296–304

[29] General Electric (GE) wind turbine. https://en.wind-turbine-models.com/turbines/656-general-electric-ge-1.5xle

[30] Parida A, Chatterjee D (2016) An improved control scheme for grid connected doubly fed induction generator considering wind-solar hybrid system. Int J Electr Power Energy Syst 77:112–122

[31] Singh B, Saha R, Chandra A, Al-Haddad K (2009) Static synchronous compensators (STATCOM): a review. IET Power Electron 2:297–324