Adaptive voltage control strategy for variable speed wind turbine connected to a weak network

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Abstract

In this paper Significant voltage fluctuations and power quality issues pose considerable constraints on the efficient integration of remotely located wind turbines into weak networks. Besides, 3p oscillations arising from the wind shear and tower shadow effects induce further voltage perturbations during continuous operation. This study investigates and analyses the repercussions raised by integrating a doubly-fed induction generator wind turbine into an ac network of different parameters and very weak conditions. An adaptive voltage control (AVC) strategy is proposed to retain voltage constancy and smoothness at the point of connection (POC) in order to maximize the wind power penetration into such networks. Intensive simulation case studies under different network topology and wind speed ranges reveal the effectiveness of the AVC scheme to effectively suppress the POC voltage variations particularly at very weak grid conditions during normal operation.

Introduction

With 282.5 GW installed capacity in 2012 compared with 94 GW in 2007, wind energy is potentially one of the fastest emerging renewable energy technology worldwide. Motivated by the desire to reduce fossil fuel emissions, policy makers implement incentives for increasing investment in wind energy worldwide. By the end of 2013, China possessed 91.4 GW cumulative capacity fostering its rank in the global wind market. Wind farms (WFs) are geographically constructed in remotely located areas with favorable wind speed conditions [3, 4]. The structure of such locations is rather weak with lower fault level due to long feeders' (high impedance) connections. Moreover, significant voltage fluctuations and power quality/stability challenges pose substantial constraints on the efficient integration of wind power into weak networks. On the other hand, even relatively strong networks might also encounter markedly grid impedance change owing to load variations and/or lines tripping. Typically, a weak network is liable to remarkable voltage deviation as a result of active and/or reactive power changes, worsening the point of connection (POC) voltage quality. FIn order to achieve independent control of the exchanged active and reactive power between the GSC and the grid, the converter controller (Fig. 5a) is operated in a synchronously rotating reference frame with the d-axis aligned with the grid voltage. The vector control of the GSC is dedicated to ensure a constant dc-link voltage irrespective of the transmitted power magnitude or direction and meanwhile provides sinusoidal currents. In addition, controls the reactive power exchange Qg between the converter and the grid side through adjusting Qg-ref to attain UPF or support the voltage during contingencies. urthermore, wind power vagaries due to wind speed variations and 3p oscillations resulting from tower shadow and wind shear effects exacerbate voltage perturbations and power quality as well.

Consequently, weak network connections impose dramatic wind power limitations in terms of grid structure and wind turbine (WT) output power. In addition, voltage fluctuations provoke flicker emissions which represent a serious drawback impacting power quality and restrict the captured wind power. Several serious concerns regarding voltage, frequency and system stability manifested recently due to connecting wind power plants (WPPs) to weak networks which irritated the proliferation of wind power.

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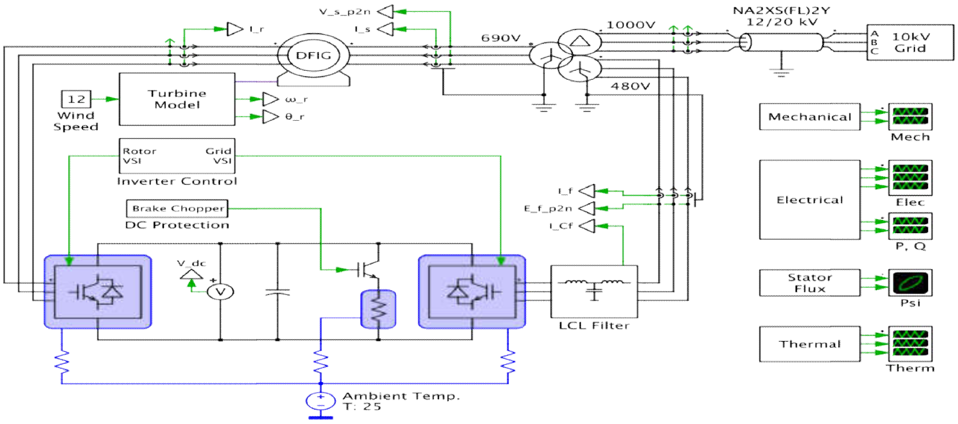
DFIG Wind Turbine System

The doubly-fed induction generator (DFIG) system is a popular system in which the power electronic interface controls the rotor currents to achieve the variable speed necessary for maximum energy capture in variable winds. Because the power electronics only process the rotor power, typically less than 25% of the overall output power, the DFIG offers the advantages of speed control with reduced cost and power losses. This PLECS demo model demonstrates a gridconnected wind turbine system using all of PLECS' physical modeling domains. The system model includes a mechanical model of the blades, hub, and shaft, a back-to-back converter including thermal loss calculations, a magnetic model of the three-phase transformer, and the transmission line and grid.

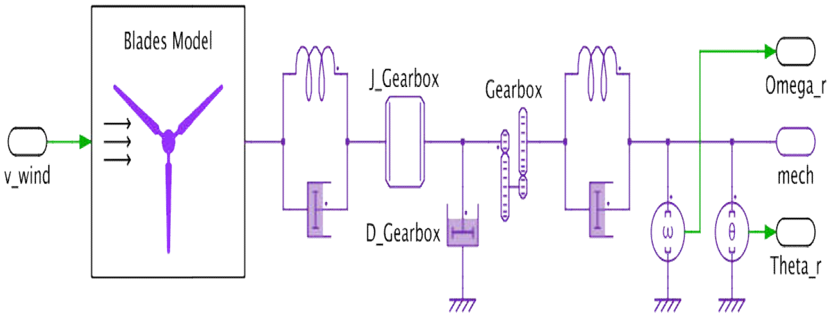
Power Circuit

The electrical power circuit consists of a DFIG, whose stator is directly connected to the grid via a transformer, while the rotor winding is connected via slip rings to a back-to-back converter. The grid-side of the converter is connected to the tertiary winding of the transformer, which feeds the generated power into the 10 kV medium voltage network through a 20 km-long cable. The transmission line is modeled with a distributed parameter line component.



Mechanical Drive train

The machine’s rotor, and the gearbox, hub and blades of the propeller together make up the mechanical part of the wind turbine. They are coupled elastically with each other, which introduces resonant oscillations into the system.



The value of the wind torque applied on the turbine blades comes from a look-up table, where the value varies against the wind and shaft rotation speeds (transformed to the high-speed side of the gearbox).

Magnetic Transformer Circuit

The three-winding transformer is built up with primitive components from the PLECS Magnetic component library. Compared to a conventional model using a purely electrical equivalent circuit, the layout of the core structure is more intuitive to understand and it is possible to model complex non-linear effects like saturation and hysteresis in the three-leg core.

Control

The back-to-back converter comprises separate machine-side and grid-side portions, which are connected with each other via a DC-link capacitor.

The machine-side converter regulates the torque of the DFIG and thus the rotational speed with a double loop structure, where the outer speed loop generates the reference signal for the inner current loop. The current control is carried out in rotational framework (d-q) with stator flux orientation. In addition, the machine-side

Operation

The conversion of the energy of the wind into more useful forms can be done using a rotor fitted with blades or sails. Note that a suitable location needs to be chosen for the WECS, preferably an open area Also; some general locations lend themselves far better than others for WECS. See Wind power

Windmills

A windmillis a mill powered by the wind. It allows reducing a solid or coarse substance into pulp or minute grains by crushing, grinding, or pressing.

Wind pumps

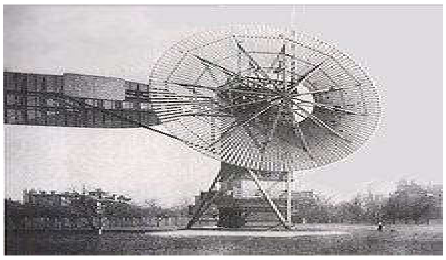
A windpumpis a type of windmill used for pumping water from a wellor draining land.

Wind turbines

The most modern generations of windmills are more properly called wind turbines, or wind generators, and are primarily used to generate electricityand electrical energy. Modern windmills are designed to convert the energy of the wind into electricity. The largest wind turbines can generate up to 6MW of power (for comparison a modern fossil fuel power plantgenerates between 500 and 1,300MW).

With increasing environmental concern, and approaching limits to fossil fuelconsumption, wind powerhas regained interest as a renewable energysource. It is increasingly becoming more useful and sufficient in providing energy for many areas of the world, especially in temperate climates.

History



Charles Brush'swindmill of 1888, used for generating electricity.

Wind power has been used as long as humans have put sailsinto the wind. For more than two millennia wind-powered machineshave ground grain and pumped water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel. Wind-powered pumps drained the polders of the Netherlands, and in arid regions such as the American mid-westor the Australian outback,wind pumps provided water for live stock and steam engines.

Generator characteristics and stability

Induction generators, which were often used for wind power projects in the 1980s and 1990s, require reactive powerfor excitationso substationsused in wind-power collection systems include substantial capacitorbanks for power factor correction. Different types of wind turbine generators behave differently during transmission grid disturbances, so extensive modelingof the dynamic electromechanical characteristics of a new wind farm is required by transmission system operators to ensure predictable stable behaviour during system faults. In particular, induction generators cannot support the system voltage during faults, unlike steam or hydro turbine-driven synchronous generators.

Offshore wind power

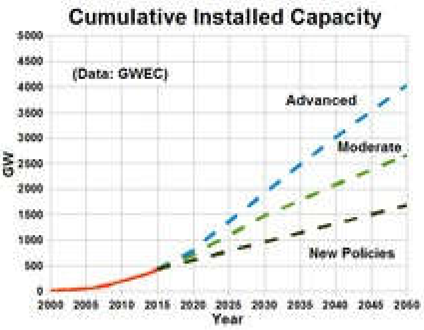
The world's second full-scale floating wind turbine(and first to be installed without the use of heavy-lift vessels), Wind Float, operating at rated capacity (2 MW) approximately 5 km offshore of Póvoa de Varzim, Portugal

Wind power capacity and production

Worldwide there are now over two hundred thousand wind turbines operating, with a total nameplate capacityof 432,000 MW as of end 2015. The European Unionalone passed some

100,000 MW nameplate capacities in September 2012; while the United States surpassed 75,000 MW in 2015 and China's grid connected capacity passed 145,000 MW in 2015.

Growth trends



Worldwide installed wind power capacity forecast (Source: Global Wind Energy Council)

In 2010, more than half of all new wind power was added outside of the traditional markets in Europe and North America. This was largely from new construction in China, which accounted for nearly half the new wind installations (16.5 GW).

Capacity factor

Since wind speed is not constant, a wind farm's annual energyproduction is never as much as the sum of the generator nameplate ratings multiplied by the total hours in a year. The ratio of actual productivity in a year to this theoretical maximum is called the capacity factor. Typical capacity factors are 15–50%; values at the upper end of the range are achieved in favourable sites and are due to wind turbine design improvements.

Online data is available for some locations, and the capacity factor can be calculated from the yearly output. For example, the German nationwide average wind power capacity factor over all of 2012 was just under 17.5% (45867 GW·h/yr / (29.9 GW × 24 × 366) = 0.1746), and the capacity factor for Scottish wind farms averaged 24% between 2008 and 2010.

Variability

Windmills are typically installed in favourable windy locations. In the image, wind power generators in Spain, near an Osborne bull.

Predictability

Wind power forecasting methods are used, but predictability of any particular wind farm is low for short-term operation. For any particular generator there is an 80% chance that wind output will change less than 10% in an hour and a 40% chance that it will change 10% or more in 5 hours.

However, studies by Graham Sinden (2009) suggest that, in practice, the variations in thousands of wind turbines, spread out over several different sites and wind regimes, are smoothed. As the distance between sites increases, the correlation between wind speeds measured at those sites, decreases.

Capacity credit, fuel savings and energy payback

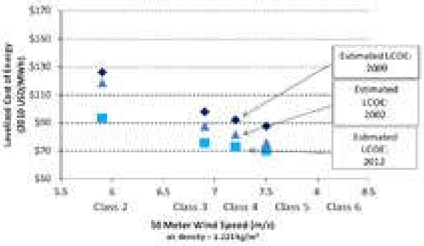
The capacity creditof wind is estimated by determining the capacity of conventional plants displaced by wind power, whilst maintaining the same degree of system security. However, the precise value is irrelevant since the main value of wind is its fuel and CO_2 savings, and wind is not expected to be constantly available.

The energy needed to build a wind farm divided into the total output over its life, Energy Return on Energy Invested, of wind power varies but averages about 20–25. Thus, the energy payback time is typically around one year.

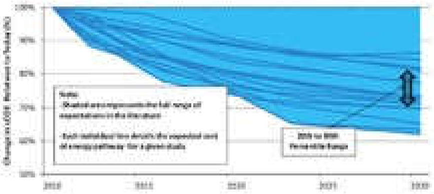
Economics

Wind turbines reached grid parity(the point at which the cost of wind power matches traditional sources) in some areas of Europe in the mid-2000s, and in the US around the same time. Falling prices continue to drive the levelized cost down and it has been suggested that it has reached general grid parity in Europe in 2010, and will reach the same point in the US around 2016 due to an expected reduction in capital costs of about 12%.

Electricity cost and trends



Estimated cost per MWh for wind power in Denmark



The National Renewable Energy Laboratoryprojects that the levelized cost of wind power in the U.S. will decline about 25% from 2012 to 2030.

A turbine blade convoy passing through Eden fieldin the U.K. (2008).

Even longer two-piece bladesare now manufactured, and then assembled on-site to reduce difficulties in transportation.

Wind power is capital intensive, but has no fuel costs. The price of wind power is therefore much more stable than the volatile prices of fossil fuel sources. The marginal costof wind energy once a station is constructed is usually less than 1-cent per kW·h.

Incentives and community benefits

U.S. landowners typically receive $3,000–$5,000 annual rental income per wind turbine, while farmers continue to grow crops or graze cattle up to the foot of the turbines. Shown: the Brazos Wind Farm, Texas.

Some of the 6,000 turbines in California's Altamont Pass Wind Farmaided by tax incentives during the 1980s.

The U.S. wind industry generates tens of thousands of jobs and billions of dollars of economic activity. Wind projects provide local taxes, or payments in lieu of taxes and strengthen the economy of rural communities by providing income to farmers with wind turbines on their land. Wind energy in many jurisdictions receives financial or other support to encourage its development. Wind energy benefits from subsidiesin many jurisdictions, either to increase its attractiveness, or to compensate for subsidies received by other forms of production which have significant negative externalities.

Small-scale wind power

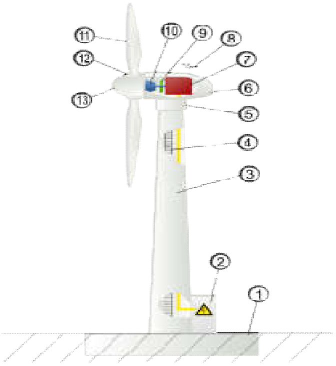
A small Quiet revolution QR5Gorlov typevertical axis wind turbineon the roof of Colston Hallin Bristol, England. Measuring 3 m in diameter and 5 m high, it has a nameplate rating of 6.5 kW.

Small-scale wind power is the name given to wind generation systems with the capacity to produce up to 50 kW of electrical power. Isolated communities, that may otherwise rely on dieselgenerators, may use wind turbines as an alternative. Individuals may purchase these systems to reduce or eliminate their dependence on grid electricity for economic reasons, or to reduce their carbon footprint. Wind turbines have been used for household electricity generation in conjunction with batterystorage over many decades in remote areas.

Public opinion

Environmental group members are both more in favor of wind power (74%) as well as more opposed (24%). Few are undecided.

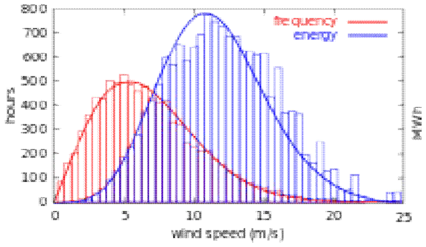
Turbine design



Typical wind turbine components : 1-Foundation, 2-Connection to the electric grid, 3-Tower, 4-Access ladder, 5-Wind orientation control (Yaw control), 6-Nacelle, 7-Generator, 8-

Wind turbinesare devices that convert the wind's kinetic energyinto electrical power. The result of over a millennium of windmilldevelopment and modern engineering, today's wind turbines are manufactured in a wide range of horizontal axis and vertical axistypes. The smallest turbines are used for applications such as battery chargingfor auxiliary power. Slightly larger turbines can be used for making small contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, have become an increasingly important source of renewable energyand are used in many countries as part of a strategy to reduce their reliance on fossil fuels.

Wind energy



Distribution of wind speed (red) and energy (blue) for all of 2002 at the Lee Ranch facility in Colorado. The histogram shows measured data, while the curve is the Rayleigh model distribution for the same average wind speed.

Wind energy is the kinetic energyof air in motion, also called wind. Total wind energy flowing through an imaginary surface with area A during the time t is:

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3,$$

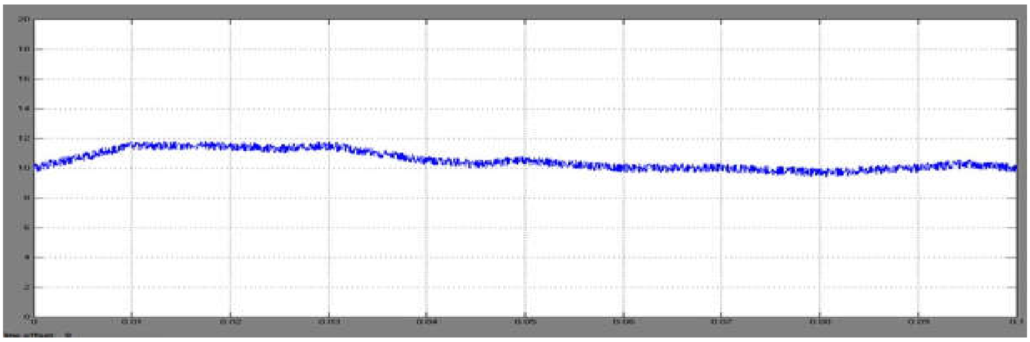
where ρ is the density of air;v is the wind speed;Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); $Avt\rho$ is therefore the mass m passing through "A". Note that ½ ρv^2 is the kinetic energy of the moving air per unit volume.

Power is energy per unit time, so the wind power incident on A (e.g. equal to the rotor area of a wind turbine) is:

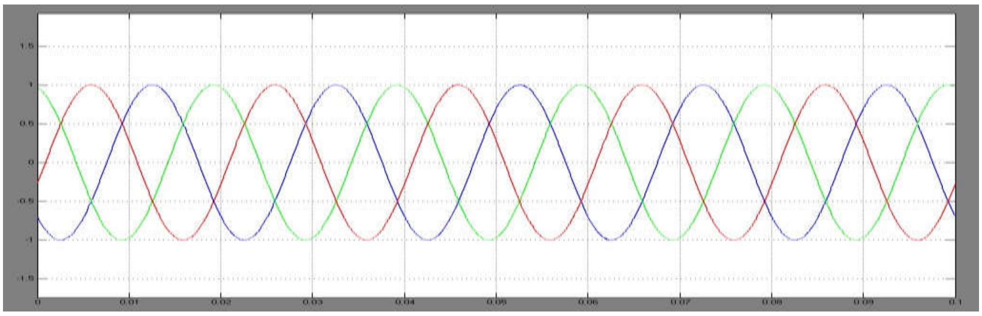
$$P = \frac{E}{t} = \frac{1}{2}A\rho v^3.$$

Wind power in an open air stream is thus proportional to the third power of the wind speed; the available power increases eightfold when the wind speed doubles. Wind turbines for grid electricity therefore need to be especially efficient at greater wind speeds.

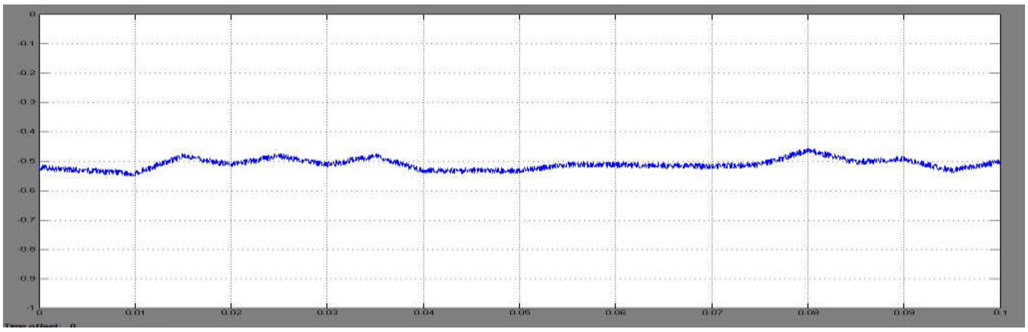
OUTPUTT WAVEFORMS:



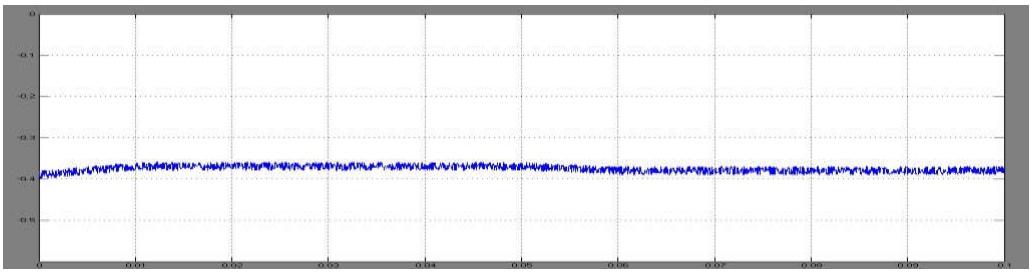
Vw : WIND SPEED



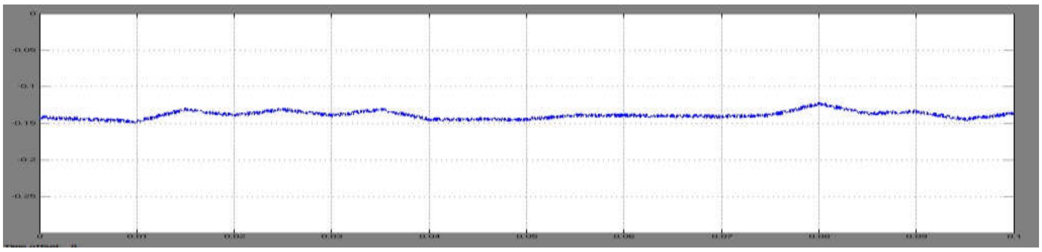
Vpoc : 3 PHASE GRID VOLTAGE (1 PER UNIT)



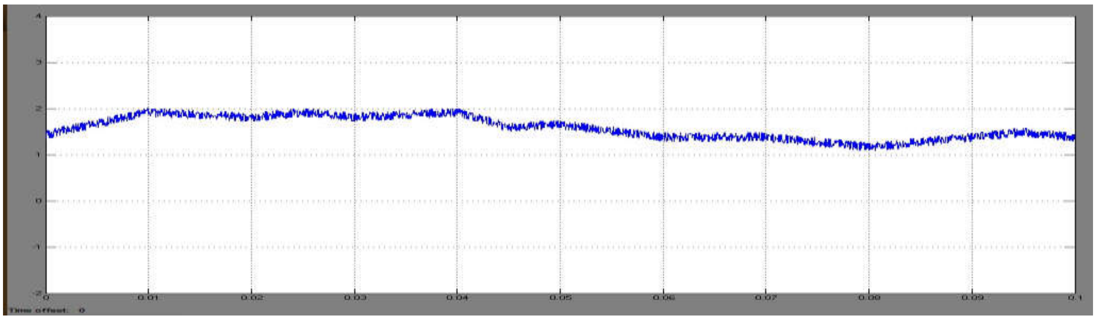
Qt : TOTAL REACTIVE POWER



Qs : SOURCE SIDE REACTIVE POWER



Qg : GRID SIDE REACTIVE POWER



Ks: PROPORTIONAL GAIN

Model analysis tools include linearization and trimming tools, which can be accessed from the MATLAB command line, plus the many tools in MATLAB and its application toolboxes. Because MATLAB and Simulink are integrated, you can simulate, analyze, and revise your models in either environment at any point.

Conclusions

This paper presents an AVC strategy for a DFIG VSWT connected to widely varying weak network parameters. As a basis of investigation, an equivalent system model is utilised to realize the voltage and active/reactive power constraints raised by integration of a wind generator to a weak host network. The associated interactions between the wind generator and the host network under different network strengths are presented. Intensive simulation case studies have been carried out to verify the effectiveness of the proposed AVC scheme. The AVC strategy showed pronounced mitigation capability with better damped performance particularly at very weak grid condition.

References

1 Lo, S., Wu, C.: ‘Evaluating the performance of wind farms in China: an empirical review’, Electra. Power Energy Syst., 2015, 69, (1), pp. 58–66

2 Edema, T., Söderholm, P.: ‘Wind power, regional development and benefit-sharing: the case of Northern Sweden’, Renew. Sustain. Energy Rev., 2015, 47, (7), pp. 476–485

3 Morgana, G., Sian, P., Piccolo, A., et al.: ‘Improving fault ride-through capability of variable speed wind turbines in distribution networks’, IEEE Syst. J., 2013, 7, (4), pp. 713–722

4 Zhao, Z., Yan, H., and Zoo, and J., et al.: ‘A critical review of factors affecting the wind power generation industry in China’, Renew. Sustain. Energy Rev., 2013, 19, (7), pp. 499–508 5 Strachan, N.P.W.,

5. Jovcic, D.: ‘Stability of a variable-speed permanent magnet wind generator with weak AC grids’, IEEE Trans. Power Deli., 2010, 25, (4), pp. 2779–2788

6 Hu, W., Chen, Z., Wang, Y., et al.: ‘Flicker mitigation by active power control of variable-speed wind turbines with full-scale back-to-back power converters’, IEEE Trans. Energy Convers., 2009, 24, (3), pp. 640–649

7 Zhang, Y., Chen, Z., Hum., et al. ‘Flicker mitigation by individual pitch control of variable speed wind turbines with DFIG’, IEEE Trans. Energy Convers., 2014, 29, (1), pp. 20–28 8 Ammar, M., Joos, G.: ‘Impact of distributed wind generators reactive power behavior on flicker severity’, IEEE Trans. Energy Convers., 2013, 28, (2), pp. 425–433

9 Zhang, Y., Hu, W., Chen, Z., et al.: ‘Flicker mitigation strategy for a doubly fed induction generator by torque control’, IET Renew. Power Gener., 2014, 8, (2), pp. 91–99

10 Chen, X., Kang, C., O’Malley, M., et al.: ‘Increasing the flexibility of combined heat and power for wind power integration in china: modeling and implications’, IEEE Trans. Power Syst., 2015, 30, (4), pp. 1848–1857 Strategy Plan Energinet.dk, 2012,

11 Kayıkcı, M., Milanovic, J.V.: ‘Reactive power control strategies for DFIG-based plants’, IEEE Trans. Energy Convers., 2007, 22, (2), pp. 389–396

12 Yang, L., Xu, Z., Østergaard, J., et al.: ‘Advanced control strategy of DFIG wind turbines for power system fault ride through’, IEEE Trans. Power Syst., 2012, 27, (2), pp. 713–722

13 Montilla-DJesus, M.E., Santos-Martin, D., Arnaltes, S., et al.: ‘Optimal operation of offshore wind farms with line-commutated HVDC link connection’, IEEE Trans. Energy Convers., 2010, 25, (2), pp. 504513–504528

14 Mohseni, M., Islam, S.M.: ‘Review of international grid codes for wind power integration: diversity, technology and a case for global standard’, Renew. Sustain. Energy Rev., 2012, 16, (6), pp. 3876–3890

15 Girbau-Llistuella, F., Sumper, A., Díaz-González, F., et al.: ‘Flicker mitigation by reactive power control in wind farm with doubly fed induction generators’, Electr. Power Energy Syst., 2014, 55, (1), pp. 285–296