WIND POWER INTEGRATION INTO WEAK POWER SYSTEMS AND VARIABLE SPEED WIND TURBINE

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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.

Keywords- *Adaptive voltage control (AVC), Point of connection (POC), doubly-fed induction generator (DFIG), Wind Turbine (WT).*

1 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 capacities 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. Furthermore, 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. Despite the steady growth, onerous challenges impede wind power development in China. Owing to long distances between territories with high-density of wind power and load center, curtailment rate reached about 15– 25% in Northern China during 2012. The latter resulted in $1.6 billion nationwide economic loss in the same year. Additionally, voltage violations to some of the transmission networks have been detected in different regions due to the steady growth of wind power penetration. Denmark looks forward to ~50% wind power penetration by 2020 which exemplifies additional burdens on transmission as well as distribution networks. A significant portion of the Danish energy consumption is speculated via offshore WFs in the long term. Thereby, operation of wind power into weak networks is seen as an expected operating scenario in the near future in Denmark. Traditionally, variable-speed WTs (VSWTs) are operated under fixed power factor control mode as stipulated by enforced grid codes. However, such operational mode shows pronounced limitation in case of weak grid scenario. Fixed reactive power and voltage control (VC) are the two favorable operational modes in the literature for the control of VSWTs. Apart from entailing active/reactive power dispatch reactive power control mode becomes insignificant when adopted for very weak networks. Virtually, VC is the increasingly desirable weaker grid to alleviate the POC voltage/power quality issues. Besides, with the prominent wind power penetration development, ancillary services such as VC provided by VSWTs become exigent. Furthermore, VC allows for maximum reactive power compensation (RPC) during utility contingencies.

This paper is first dedicated to provide an insight into the diverse technical issues raised by integration of megawatt-level variable speed doubly-fed induction generator (DFIG) into a weak network in light of network characteristics, operational limits and wind speed variations. Other authors have investigated weak networks in terms of short-circuit capacity ratio (SCR, the ratio between the POC short circuit power to the maximum apparent power of the wind generator) but with fixed feeder X/R ratio (the ratio between the grid reactance to its resistance, viz., stands for the grid impedance angle). Besides, the design of the relevant VC relies on fixed adaptive gains to improve the POC voltage performance. The novelty of this paper lies in a proposed adaptive VC (AVC) scheme reliant on network parameters to continually mitigate POC voltage variations for very weak networks with widely varying SCR as well as X/R ratios under different operating conditions. A reactive power dispatch strategy to manage the reactive power flow from/to the wind generator (WG) is proposed. Additionally, the paper not only quantifies the system reactive power associated with the network parameters change but also the reactive power sharing inside the WG and identifies the proper grid side converter (GSC) rating to tackle the voltage perturbations at the conceivable system strengths and operating point. Furthermore, the overall system stability is investigated using AVC via identifying the safe operating regions for a wide range of system parameters. In a broader context, the proposed AVC aims at facilitating wind power penetration into weak power systems. The RPC is realized primarily via the DFIG inherent stator reactive power as well as an over-sized GSC which manipulates the reactive power deficit to address voltage disturbances. Moreover, a reactive power dispatch strategy to manage the reactive power coordination between the DFIG and the GSC is also presented.

2. POWER CIRCUIT OF DFIG WT SYSTEM

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.

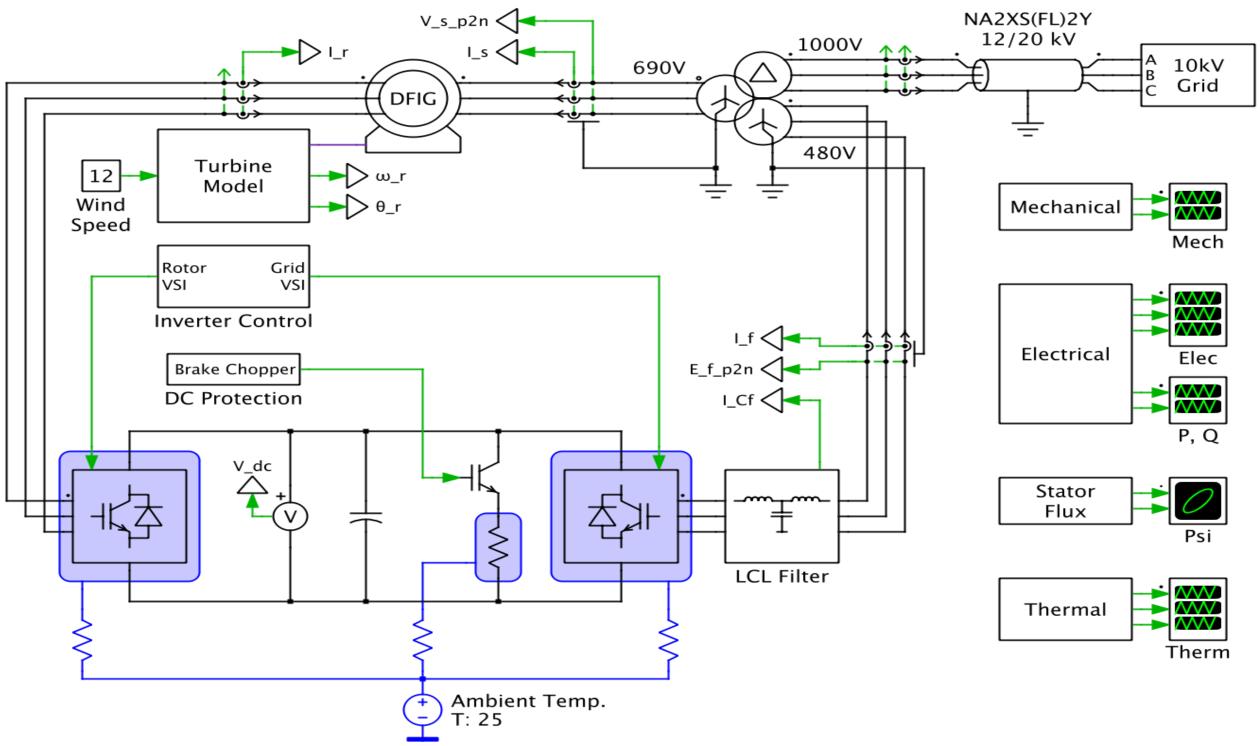


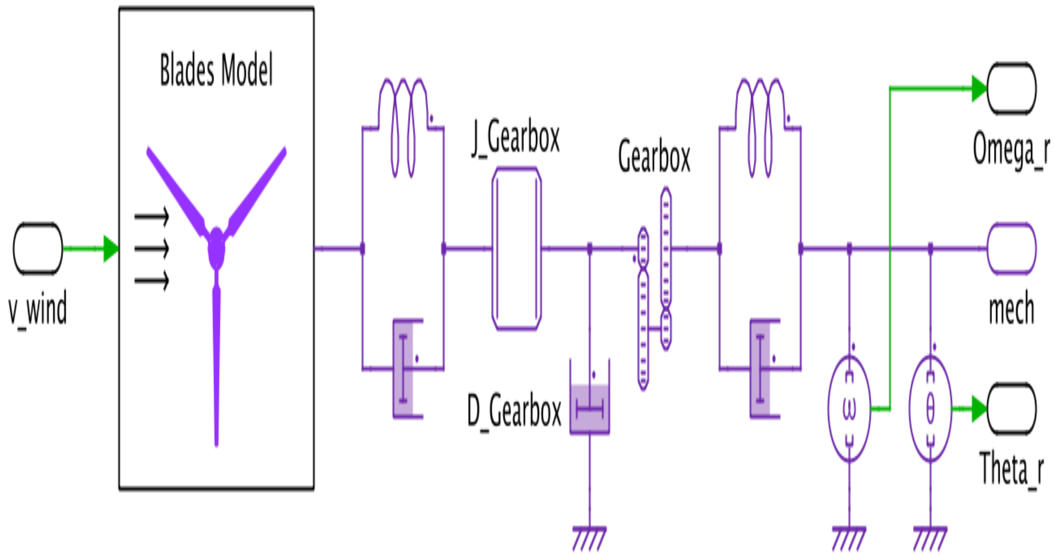
Fig.1 Circuit model of DFIG WT test system

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.

Mechanical Drive train

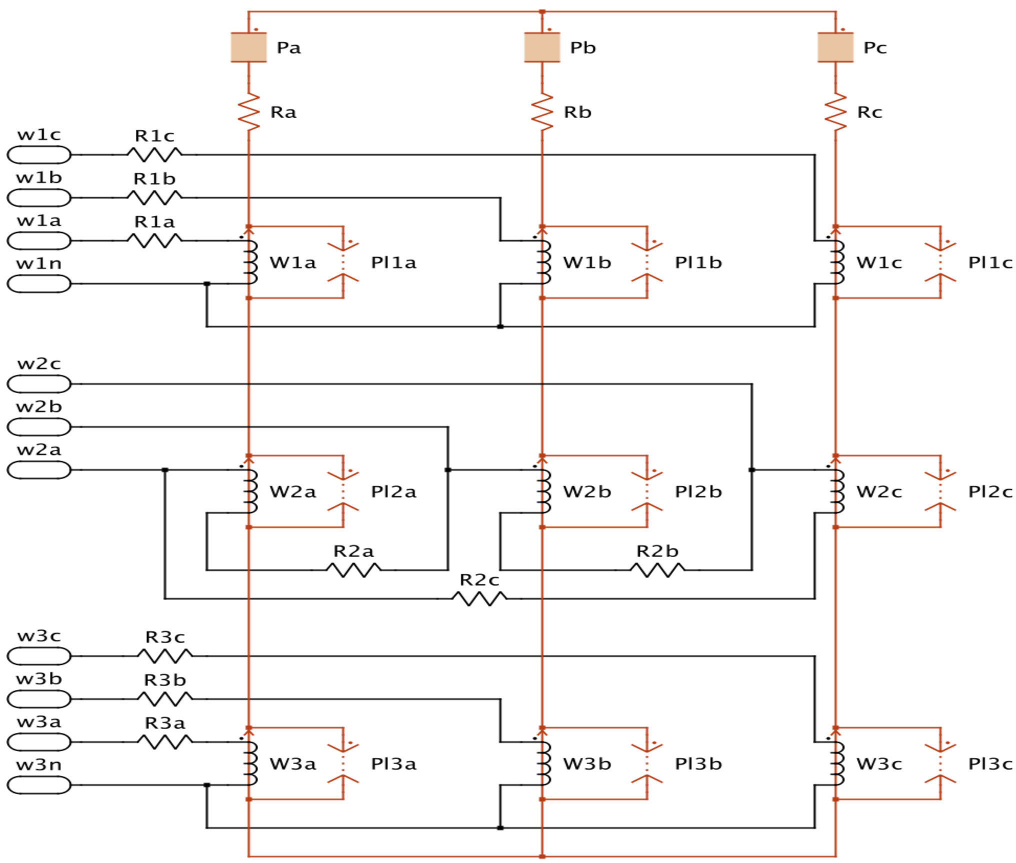
The machine' s rotor, and the gearbox, hub and blades of the propeller together make up the mechanical part of the wind turbine. They are coupled elastically with each other, which introduces resonant oscillations into the system.



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 converter also regulates the reactive power injection of the DFIG.

The grid-side converter transfers the active power from the machine-side converter into the grid through an LCL filter, and maintains the DC-link voltage at 950 VDC. The methods of active damping, feed forward as well as integrator anti-windup are adopted for the PI controllers, and the converters operate using space vector PWM (SVPWM) modulation.

3. MODEL OF THE GRID CONNECTED DFIG WT TEST SYSTEM

Fig. 2a illustrates a schematic representation of the DFIG WT test system model. The model comprises a VSW, drive train, gear box, DFIG and two back-to-back AC– DC– AC partial converters, namely, GSC and generator-side (rotor side) converter (RSC). The WT is connected at the POC to the host network by means of an interface transformer and transmission line. A typical two-level control scheme is devoted to control the DFIG WT system. A WT control is utilized to regulate WT mechanical output power through appropriately adjusting both the pitch angle and the rotor speed according to the maximum power point tracking (MPPT) tracking. The blade pitch angle BPA controller model used.

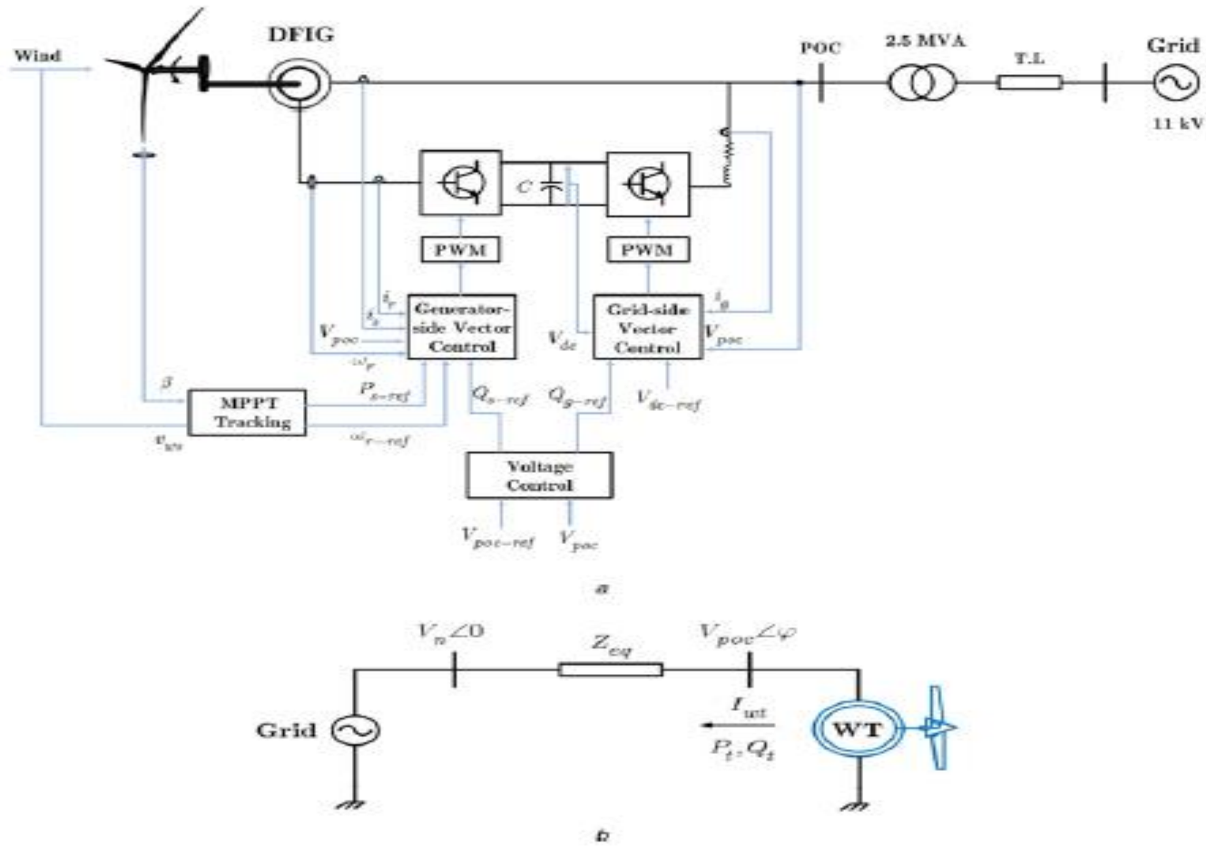


Fig. 2 Schematic representation of the DFIG WT test system model
a) Block diagram of a grid-connected DFIG WT test system
b) Grid-connected DFIG WT equivalent system

4. SIMULINK MODEL AND RESULT of THE SYSTEM

This section provides a set of simulation test cases to verify the DFIG dynamic response using different control schemes and PLL structures under different fault scenarios. Conventional control method refers to the basic GSC and RSC controllers and the SRF-PLL. Whereas, control method 1 refers to the GSC DDSRF current controller and the DDSRF-PLL and control method 2 denotes the GSC controller using DDSRF current controller, proposed RSC controller and DSOGI-FLL. Moreover, the system compliance to the grid codes requirements during faulty conditions is also examined. Figure 5.14 depicts the test system used for the simulation where a 2

MW DFIG WT is connected to a weak grid of SCR=3 and X/R=10. The system is simulated in the MATLAB/SIMULINK platform. As the wind speed is not expected to encounter significant change during a fault, the simulations are carried out at the nominal wind speed of the WT (10 to 11.4 m/s).

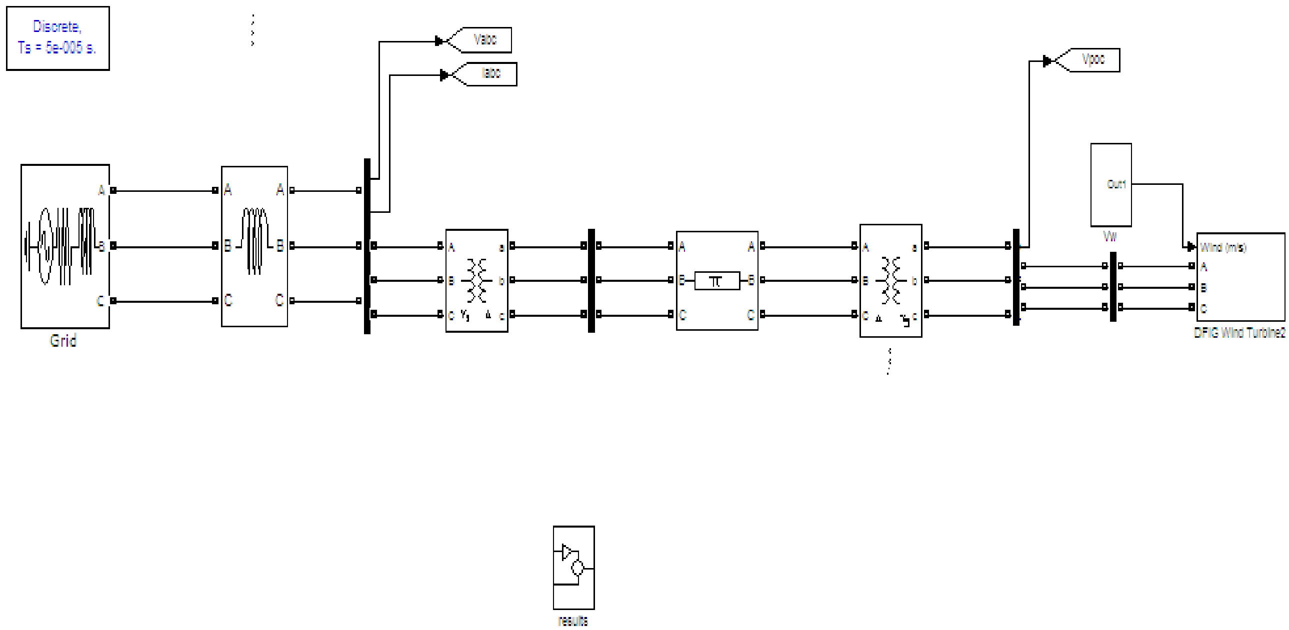


Fig.3 Simulink model of DFIG WT system

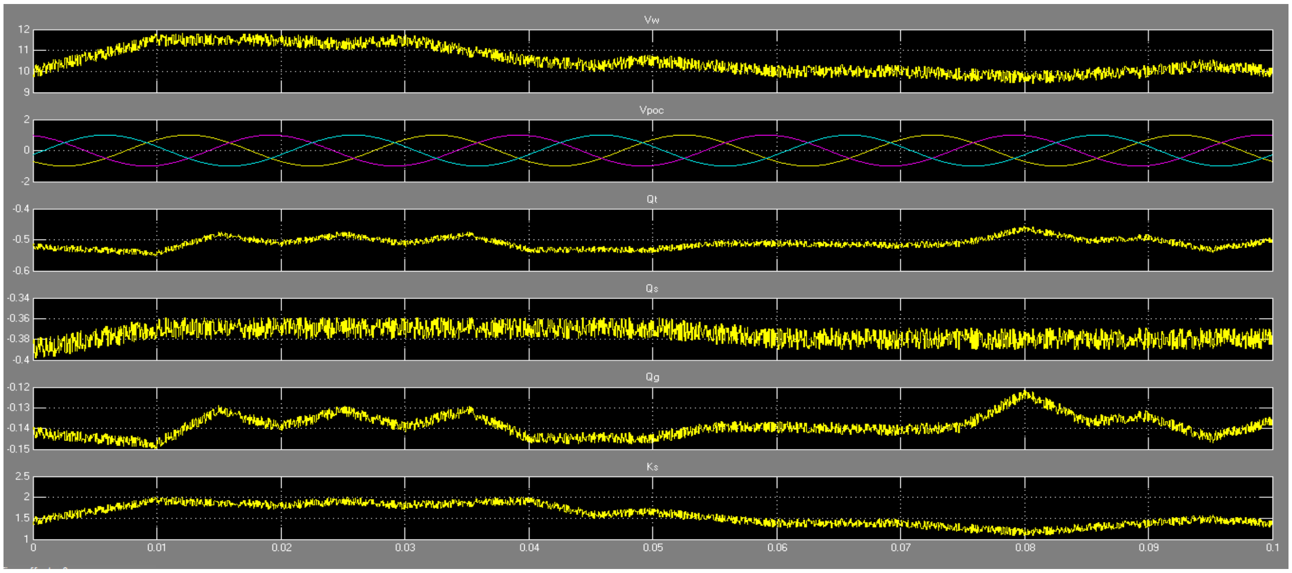


Fig.4 output

Fig.4 gives details Vw wind speed which is measured in m/s, Vpoc is point of connection (POC) voltage quality Qs and Qs are grid and stator side reactive power which is measured in p.u Ks open loop gain illustrates a long-term system response to a very weak grid condition which corresponds to SCR of 1 and X/R of 0.5. As it shows, POC voltage fluctuations are induced due to higher network impedance, wind speed variations and also 3p oscillations. Consequently, higher reactive power absorption Qt is required in this case to compensate the voltage as seen in above figure.

CONCLUSION

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 utilized 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.

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