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Simulation and Modeling of DFIG Wind Farm in Wind Energy Conversion System

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Abstract

In today's world as there is surge in power demand, there is need for alternative energy sources and Wind Energy generation systems are now gaining popularity as they provide better power quality and active power control. Complete modeling and simulation of wind turbine driven doubly fed induction generator is presented in this paper. There is rapid growth of variable speed Wind Energy Conversion Systems (WECS) due to advances in power electronics technology. Wind turbines which employ a doubly-fed induction generator (DFIG) usually have a wound rotor induction generator and an AC/DC/AC IGBT based PWM converter. A remote fault occurs on 120KV system and its steady state and dynamic analysis is described in this paper . The complete wind farm is modeled and simulated in the MATLAB.

Keywords: Doubly Fed Induction Generator (DFIG), Pulse Width Modulation (PWM),Wind Energy Conversion Systems(WECS)

1. INTRODUCTION

The demand of energy is increasing day by day and the conventional energy sources are depleting at a very fast rate and also possess a threat to environment, so there is an excessive interest towards environment friendly and feasible energy sources like wind energy, solar energy, biomass, wave energy etc. Out of all these sources wind energy is the most likable choice because of its performance and economical aspects. At the end of 2017 the overall wind capacity worldwide reached to 539291 MW. Most of the countries have achieved high level of wind production by the end of 2017 such as China produces 18839235 MW of wind energy which is 35% of total worldwide production followed by USA and Germany which produces 89077MW and 56132 MW which is 17% and 10% of total worldwide production respectively. India is ranked fourth with 32848MW which is 6% of total worldwide production and is expected to add additional 2.5-3 GW in financial year 2019[8].

Wind Energy Conversion system (WECS) is a power technology that has made vast progression from the last two decades due to advancement in wind power technologies and its control and modulation techniques. At present out of Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous generator (PMSG), DFIG with vector control is in more demand because of their high performance variable speed drive and generating applications. WECS using Doubly Fed Induction Generator (DFIG) have their stator windings connected directly to the three phase constant frequency grid and rotor windings are connected to back to back PWM converters. There is a multi-stage gear box in this type of drive. By the use of DFIG in WECS maximum power, smoother grid connection, high controllability and reactive power compensation using back to back power converters can be accomplished by approximately 30%. To adjust speed, turbine pitch control is used which maximizes the power which is generated at a given wind speed. If the rotor current is governed by applying field oriented control by having double sided PWM inverters then power possessed by the power converter is a small fraction of the total system. DFIG with three stage gearbox is considered to be lightest, low cost solution with standard equipment's. In this paper a wind farm (WECS) has been modeled and simulated using DFIG. By using vector control scheme the converters have been controlled so that maximum power can be extracted from the wind [1, 3, 4, 6].

In this paper an example is taken in which there is a remote fault which occurs on the 120KV system and at 0.03 seconds 0.5 pu voltage drop is formulated and steady state and dynamic response of the system due to voltage sag is examined.

The paper is classified as follow: Section 1 presents Introduction as well as objective of the work. Section II describes basic concepts and system description . Section III describes system model and Simulation of wind farm developed in MATLAB Simulink. Section IV gives the results and conclusion.

2. BASIC CONCEPTS AND SYSTEM DESCRIPTION

WECS works on the principle which converts the kinetic energy present in the wind into mechanical energy by producing torque and power is extracted by the wind turbine. The performance is mainly characterized by the way how power varies with the wind speed. The magnitude of power depends on the air density and the wind velocity. The wind power which is developed by the turbine is given by equation (1) [2,5]:

$$P = \frac{1}{2} C_P \rho A V^3 \tag{1}$$

Where C_P is the wind power coefficient, ρ is the air density (equal to 1.225kg/m^3 at sea level at temperature

T=288K),A is the area of the turbine blades in m^3 and V is the wind velocity in m/sec. The fraction of kinetic energy which is converted into mechanical energy by the wind turbine is given by the power coefficient C_P.It is a function of blade pitch angle (β) and tip speed ratio (TSR) (λ).Tip speed ratio is the ratio of turbine blade linear speed and wind speed given by:

$$\lambda = \frac{R\omega}{V} \tag{2}$$

Substituting (2) in (1), we have:

$$P = \frac{1}{2} C_p(\lambda)\rho A \left(\frac{R}{\lambda}\right)^3 \omega^3 \tag{3}$$

The corresponding output torque of the wind turbine is given by:

$$T_{turbine} = \frac{1}{2}\rho C_P \, {}^{V}/_{\lambda} \tag{4}$$

Where R is the radius of the wind turbine rotor (m).Power coefficient is maximum at a specific value of tip speed ratio. Maximum power can be extracted by the wind turbine by operating the turbine at variable speed. The turbine C_P curves are displayed in Figure 1 which follows cubic relationship. The turbine power, tip speed ratio (λ) and C_P values are displayed in Figure 2 as a function of wind speed in which wind speed is taken as 15m/s, the turbine output power is 1 pu of its rated power, the pitch angle is 8.7 deg and the generator speed is 1.2 p u. The variable speed induction generator gives flexible rotor speed characteristics which is advantageous over synchronous generator which gives constant speed characteristics.

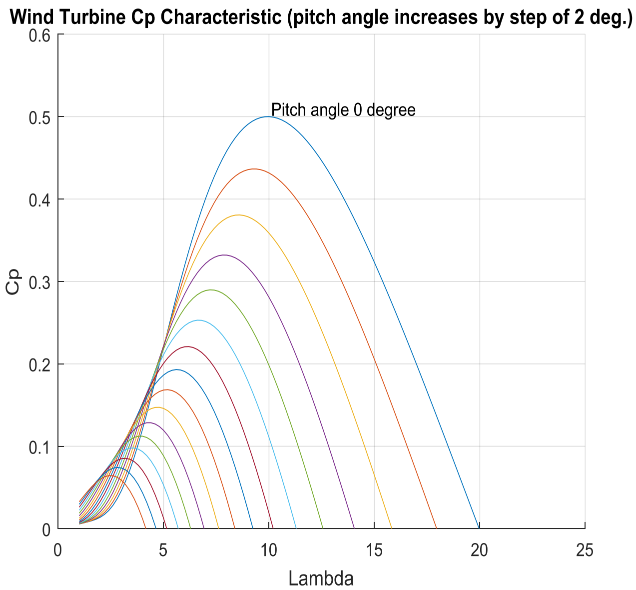

Figure 1. Wind Turbine Characteristics

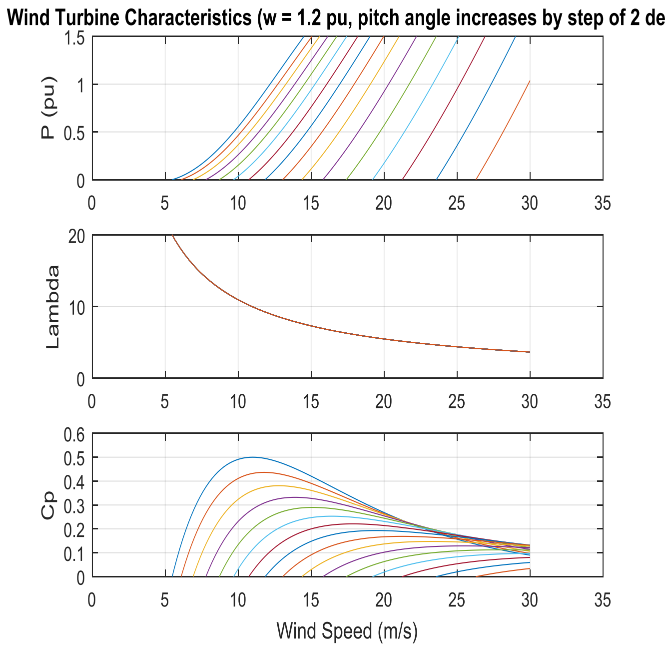

Figure 2. Turbine power, Tip speed Ratio and C_P curves

3. MODEL DESCRIPTION

Fig 3 shows the basic model of DFIG which is transferring power from wind to electric grid. In the model described in this paper the stator of the wound rotor induction motor is connected to three phase grid and rotor is connected via back to back PWM voltage source inverters having common dc link. To control Power flow between the AC side and DC grid side converter is maintained. The rotor excitation is provided by motor side power converter which helps in active and reactive power control on both stator and rotor sides. DFIG can be used as a generator or motor also at sub synchronous and super synchronous speed, thus giving four possible operating modes but in WECS only two quadrant operation is required[7,10].

In this paper the wind farm model is designed having six 1.5 MW wind with total capacity of 9MW of turbines connected to a 25KV distribution system transferring power to a 120 KV grid via 30Km, 25KV feeder. Wind turbines deploying a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT based PWM converter. The stator winding of DFIG is directly connected to the 50Hz grid while rotor is fed through AC/DC/AC converter at variable frequency. By optimizing the speed of the turbine, the DFIG technology extracts maximum energy from the wind for low wind speeds as mechanical stresses are minimized on the turbine during sudden strong rush of wind.

The constant wind speed is taken as 15m/s in this example. Speed of turbine is kept at 1.2p u by using Torque controller in the control system. The reactive power produced by the wind turbine is maintained at 0 MVAR.

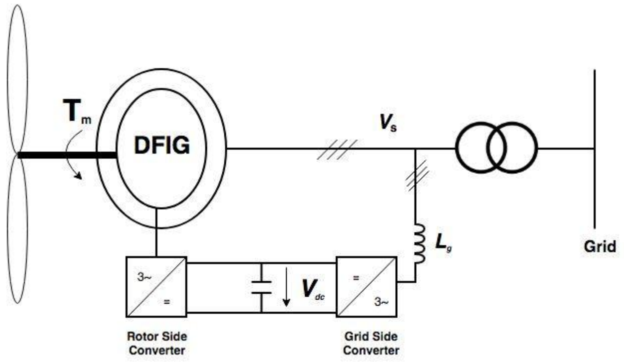

Figure 3. Wind Turbine Driven DFIG

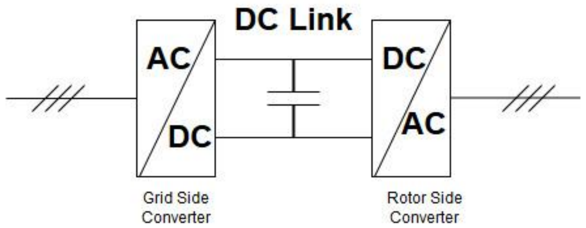

Figure 4. Two Back to Back PWM

The power output from back to back PWM convertors through common DC link is feed to the grid. The convertor connected to induction generator side behaves as a PWM rectifier and connected to grid side acts as PWM invertor as DFIG works in super synchronous mode. PWM rectifier converts variable voltage and frequency at machine rotor terminals to DC voltage. The output voltage is given by equation (5) [9]:

$$V_r = \left(\frac{3\sqrt{2}}{\pi}\right)\left(\frac{\sqrt{3}}{\sqrt{2}}\right) V_{ds}\, n_i \quad (5)$$

LC filter is connected in DC link so as to get smooth DC output voltage. DC link capacitor provides isolation between the two convertors as shown in figure 4.

The model shown in figure 5 give detailed representation of power electronic IGBT convertors. The model must be discretized at a small time step of approximately 5 micro seconds to achieve an acceptable accuracy with 1620 Hz and 2700 Hz switching frequencies. The above model is well suited for observing harmonics and control system dynamic performance over typically hundreds of milliseconds to one second. This example uses an initial state vector to start the simulation from steady state.

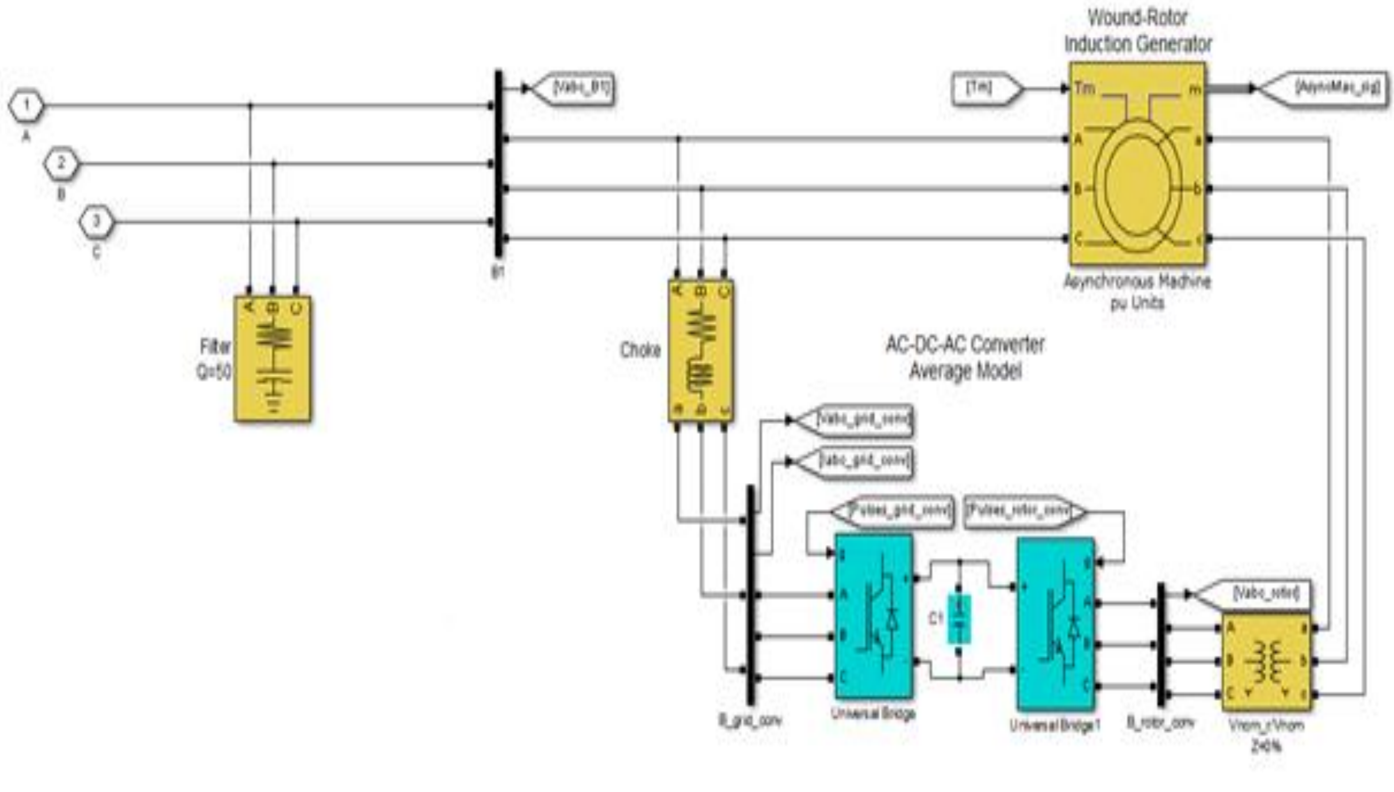

Figure 5. DFIG wind Farm Model

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4. RESULTS AND CONCLUSIONS

Fig 6 shows active power P(MW),reactive power Q(MVAR),DC voltage(V_{DC}),wind speed W_r(pu)when a remote fault on the 120-KV system occurs. In this example the simulation starts in steady state by initializing all the states as due to inertia of turbine time if initial state is not set then time constant will be large. The values of DC power and wind speed is set to 1150 V and 1.2 p.u respectively. Fig 7 shows active power P (MW), reactive power Q(MVAR),DC voltage(V_{DC}),wind speed W_r(pu) when steady state is reached and fault is cleared .

In this paper an example is taken in which there is a remote fault which occurs on the 120KV system and at 0.03 seconds 0.5 pu voltage drop is formulated and steady state and dynamic response of the system due to voltage sag is examined. Wind farm initially produced 9 MW and the speed of turbine is kept at 1.2 pu of the generator synchronous speed. The DC voltage and the reactive power is kept at 1150V and 0 MVAR respectively. All of a sudden the positive sequence voltage crumbles to 0.5 pu at time duration t=0.03 s which causes oscillation on the DC bus voltage and on the output power of DFIG.As control system in a bid to adjust the voltage on DC bus at its fixed value of 1150 V and reactive power bus at its fixed value of 0 MVAR which occurs during voltage sag, then it takes approximately 4 cycles for a system to recover from a fault that occurred in 12KV line.

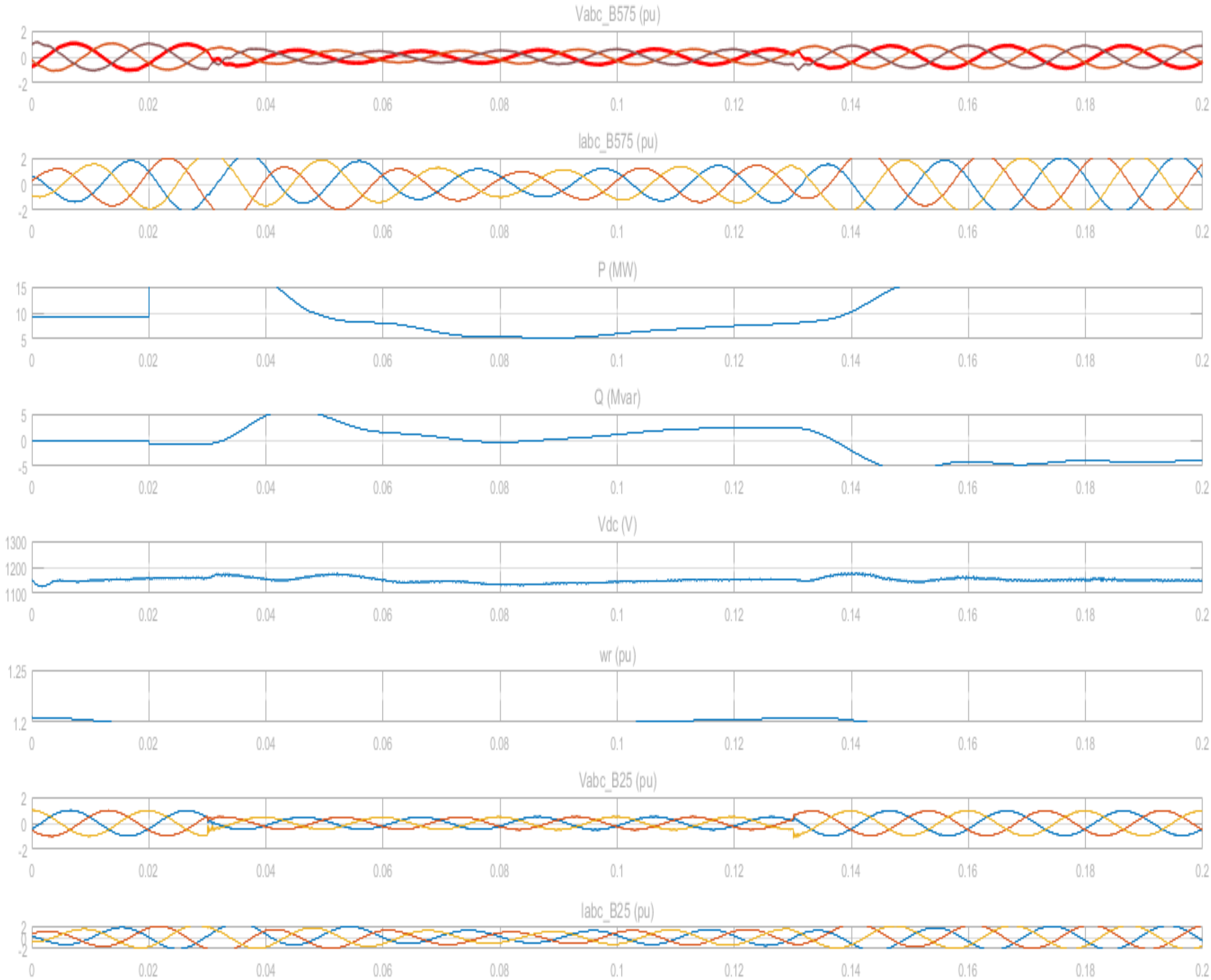

Figure 6. Machine Output waveform at Fault

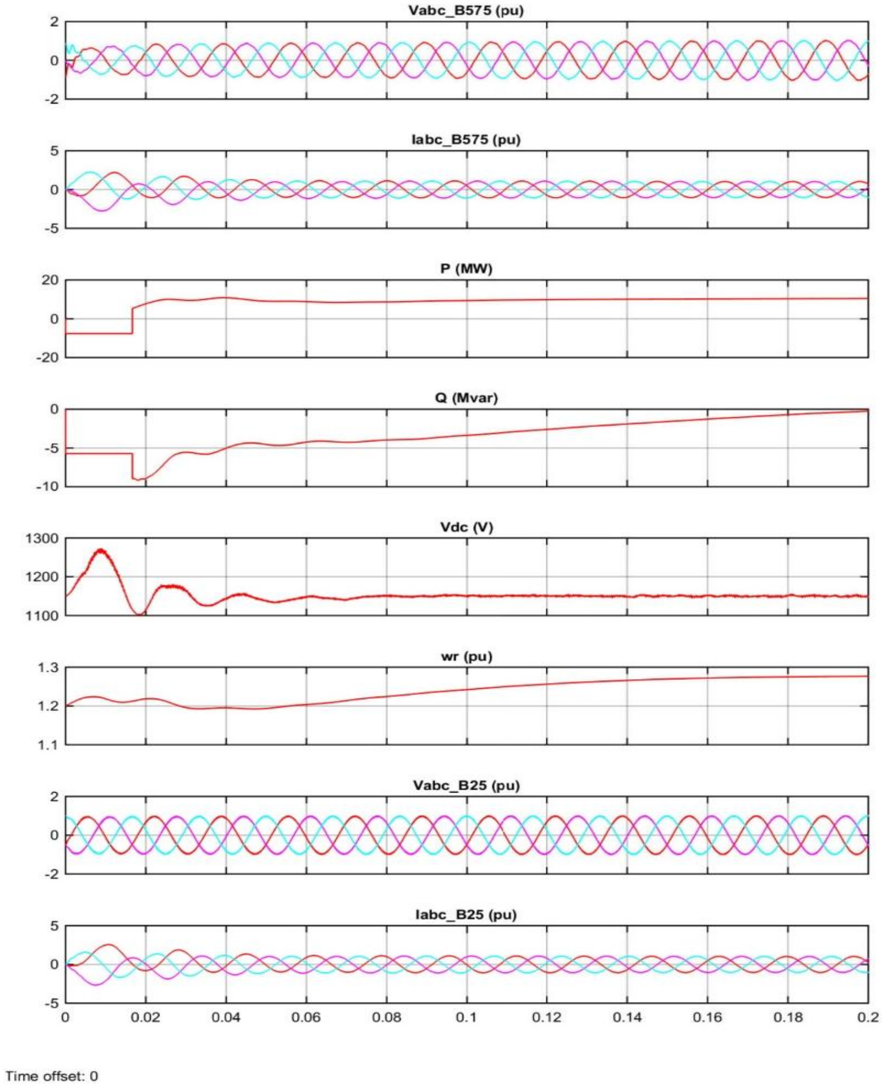

Figure 7. Steady state machine output waveform.

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