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Research Article

Novel Simplified Model for Asynchronous Machine with Consideration of Frequency Characteristic

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The frequency characteristic of electric equipment should be considered in the digital simulation of power systems. The traditional asynchronous machine third-order transient model excludes not only the stator transient but also the frequency characteristics, thus decreasing the application sphere of the model and resulting in a large error under some special conditions. Based on the physical equivalent circuit and Park model for asynchronous machines, this study proposes a novel asynchronous third-order transient machine model with consideration of the frequency characteristic. In the new definitions of variables, the voltages behind the reactance are redefined as the linear equation of flux linkage. In this way, the rotor voltage equation is not associated with the derivative terms of frequency. However, the derivative terms of frequency should not always be ignored in the application of the traditional third-order transient model. Compared with the traditional third-order transient model, the novel simplified third-order transient model with consideration of the frequency characteristic is more accurate without increasing the order and complexity. Simulation results show that the novel third-order transient model for the asynchronous machine is suitable and effective and is more accurate than the widely used traditional simplified third-order transient model under some special conditions with drastic frequency fluctuations.

1. Introduction

Voltage sag is a common phenomenon during power system failure, whereas system frequency remains constant in large-scale power systems. Consequently, traditional power system modeling and simulation are focused on the voltage characteristics of power equipment with less consideration of the frequency characteristic. However, with the high penetration of distributed generation [1, 2], system frequency will fluctuate when a random imbalance between power generation and demand exists. For example, a fault or a sudden change in power loading in a microgrid [3–5] will cause a relatively large frequency fluctuation because the system inertia is small. In addition, in some isolated grids (e.g., XinJiang and Hainan power grids in China), system failures also produce frequency problems [6–9]. Thus, the frequency characteristic of equipment should be considered in power system modeling and simulation.

Asynchronous machines, which contain asynchronous induction motors and induction generators, are important equipment in power systems. Dynamic load comprises induction motors [6–15] and a large number of wind power generators, such as induction generators or doubly fed induction generators (DFIGs) [16–22]. Third-order electromechanical transient model for asynchronous machines is widely used in power system simulation. The traditional form of this model cannot represent the frequency characteristic of asynchronous machines because this simplified model only assumes that the frequency is constant and ignores the first derivative of frequency during derivation. The simulation

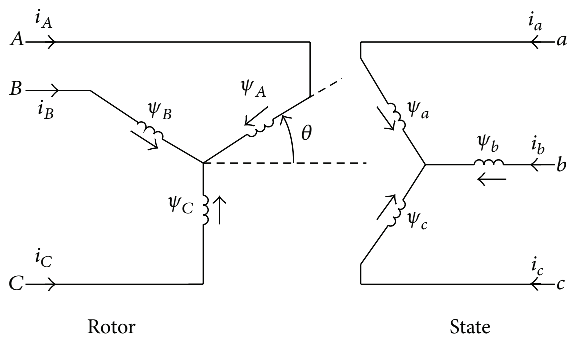

FIGURE 1: Stator and rotor circuits of an induction motor.

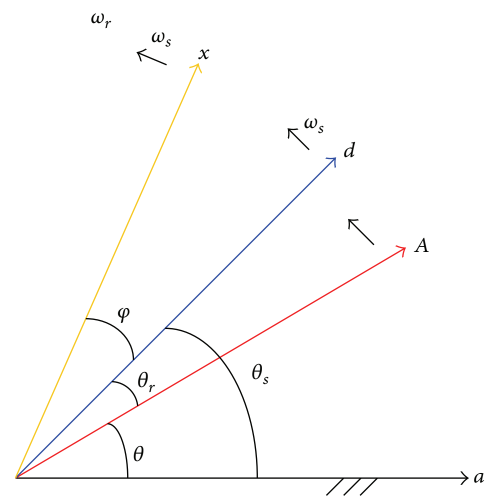

FIGURE 2: Convolution vector diagram.

results are acceptable when using the traditional third-order transient model under the conditions that frequency fluctuates slightly or without consideration of the frequency fluctuation. However, when studying the power grid with high penetration of distributed generation, the use of the traditional third-order transient model will generate significant error in the simulation result in contrast to the field measurement. Load modeling with consideration of the frequency and the voltage is discussed in [8]. The improved measure-based load modeling can reflect the real load dynamic characteristic well. A novel frequency regulation by DFIG-based wind turbines (WTs) used to coordinate inertial control, rotor speed control, and pitch angle control is studied in [23]. The coordinated control enhances frequency regulation capability and damps frequency oscillations. The capability of WTs to participate in the primary frequency control and to offer primary reserve is discussed in [24], in which transient frequency support and permanent frequency response were also investigated.

To represent the voltage and the frequency characteristics of an asynchronous machine during simulation, this paper proposes a novel simplified third-order transient model by redefining the variables and parameters of the traditional model. In this novel simplified third-order model, the definition of transient variable provides a clear physical interpretation. The novel simplified third-order model can accurately represent the frequency characteristic of asynchronous machines. Meanwhile, this variable will not increase the order and complexity of the model. Finally, simulation results verify the effectiveness and accuracy of the novel simplified third-order transient model in power system simulation.

2. Park Model of Asynchronous Machine

Figure 1 shows the circuits applicable to the analysis of an asynchronous machine. The stator circuits comprise three-phase windings a, b, and c distributed 120° apart in space. The rotor circuits contain three distributed windings A, B, and C.

Neglecting saturation, hysteresis, and eddy currents and assuming a purely sinusoidal distribution of flux waves, the machine equations can be written as follows [25].

The stator and rotor voltage equations are given by

$$\mathbf{u}_{abc} = R_s \mathbf{i}_{abc} + \frac{d\boldsymbol{\psi}_{abc}}{dt}, \qquad \mathbf{u}_{ABC} = R_r \mathbf{i}_{ABC} + \frac{d\boldsymbol{\psi}_{ABC}}{dt}, \tag{1}$$

where $\mathbf{u}$ represents voltage, $\mathbf{i}$ represents current, ψ represents the flux linking the winding denoted by the subscript, R_s is the stator phase resistance, R_r is the rotor phase resistance, and subscripts abc and ABC are the stator and rotor windings, respectively.

θ is defined as the angle by which the axis of the phase A rotor winding leads the axis of phase a stator winding in the direction of rotation, with a constant rotor angular velocity of ω_r:

$$\theta = \omega_r t \tag{2}$$

and with a constant slip s:

$$\theta = (1 - s)\,\omega_s t. \tag{3}$$

Figure 2 shows that the electrical angular velocity of reference frame xy and rotating reference frame dq is ω_s in rad/s, the axis of d winding leads to the axis of q winding in the direction of rotation, and axis d coincides with the axis of phase a stator winding at initial moment $t = 0$.

By applying the $dq0$ transformation equation, we obtain the following expressions as regards the transformed components of voltage, flux linkages, and currents [25].

Stator voltage equations:

$$u_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_s \psi_{qs}, \qquad u_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} - \omega_s \psi_{ds}; \tag{4}$$

rotor voltage equations:

$$u_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_s - \omega_r)\psi_{qr},$$
$$u_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_s - \omega_r)\psi_{dr}. \quad (5)$$

The terms $d\psi_{ds}/dt$ and $d\psi_{qs}/dt$ are the transformer voltages, similar to $d\psi_{dr}/dt$ and $d\psi_{qr}/dt$.

Stator flux linkage equations are as follows:

$$\psi_{ds} = L_{ss} i_{ds} + L_m i_{dr},$$
$$\psi_{qs} = L_{ss} i_{qs} + L_m i_{qr}. \quad (6)$$

Rotor flux leakage equations are as follows:

$$\psi_{dr} = L_{rr} i_{dr} + L_m i_{ds},$$
$$\psi_{qr} = L_{rr} i_{qr} + L_m i_{qs} \quad (7)$$

with $L_{rr} = L_r + L_m$ and $L_{ss} = L_s + L_m$, where L_s, L_r, and L_m are stator leakage, rotor leakage, and mutual inductances, respectively.

Eliminating phase voltage and current in terms of $dq0$ components, we obtain

$$P_e = \frac{3}{2}\left(u_{ds} i_{ds} + u_{qs} i_{qs}\right). \quad (8)$$

The air-gap torque T_e is obtained by dividing the power transferred across the air gap by the rotor speed in mechanical radians per second:

$$T_e = \psi_{qr} i_{dr} - \psi_{dr} i_{qr}, \quad (9)$$

where subscripts r and s represent the rotor and stator, respectively.

3. Traditional Simplified Asynchronous Machine Model

With the exclusion of the stator transients,

$$\frac{d\psi_{ds}}{dt} = \frac{d\psi_{qs}}{dt} = 0. \quad (10)$$

The following variables and parameters [25] are defined as

$$E'_d = -\omega_s \frac{L_m}{L_{rr}} \psi_{qr}, \qquad E'_q = \omega_s \frac{L_m}{L_{rr}} \psi_{dr},$$
$$X = \omega_s L_{ss}, \qquad X' = \omega_s \left(L_{ss} - \frac{L_m^2}{L_{rr}}\right),$$
$$T'_0 = \frac{L_{rr}}{R_r},$$
$$u'_{dr} = \frac{L_m}{L_{rr}} u_{dr}, \qquad u'_{qr} = \frac{L_m}{L_{rr}} u_{qr}. \quad (11)$$

Rewriting (7), we obtain

$$i_{dr} = \frac{\psi_{dr} - L_m i_{ds}}{L_{rr}},$$
$$i_{qr} = \frac{\psi_{qr} - L_m i_{qs}}{L_{rr}}. \quad (12)$$

The rotor voltage of the d component of (5) may be written as

$$u_{dr} = R_r \left(\frac{\psi_{dr} - L_m i_{ds}}{L_{rr}}\right) + \frac{d\psi_{dr}}{dt} - (\omega_s - \omega_r)\psi_{qr}$$
$$= \frac{1}{T'_0}\left(\frac{L_{rr}}{\omega_s L_m} E'_q - L_m i_{ds}\right) + \frac{d}{dt}\left(\frac{L_{rr}}{\omega_s L_m} E'_q\right)$$
$$+ (\omega_s - \omega_r)\frac{L_{rr}}{\omega_s L_m} E'_d. \quad (13)$$

From the above equation, $(d/dt)((L_{rr}/\omega_s L_m)E'_q)$ may be written as

$$\frac{d}{dt}\left(\frac{L_{rr}}{\omega_s L_m} E'_q\right) = \frac{L_{rr}}{L_m}\left(\frac{1}{\omega_s}\frac{dE'_q}{dt} - \frac{E'_q}{\omega_s^2}\frac{d\omega_s}{dt}\right). \quad (14)$$

Thus, (13) may be written as

$$\frac{dE'_q}{dt} = -\frac{1}{T'_0}\left[E'_q - \left(X - X'\right) i_{ds}\right] - s\omega_s E'_d + \omega_s u'_{dr} + \frac{E'_q}{\omega_s}\frac{d\omega_s}{dt}. \quad (15)$$

In a similar way, the q component of rotor voltage is given by

$$\frac{dE'_d}{dt} = -\frac{1}{T'_0}\left[E'_d + \left(X - X'\right) i_{qs}\right] + s\omega_s E'_q - \omega_s u'_{qr} + \frac{E'_d}{\omega_s}\frac{d\omega_s}{dt}. \quad (16)$$

The term $d\omega_s/dt$ is usually excluded in system simulation in previous studies, and asynchronous machine transient model equations can be rewritten as follows:

$$\frac{dE'_d}{dt} = -\frac{1}{T'_0}\left[E'_d + \left(X - X'\right) i_{qs}\right] + s\omega_s E'_q - \omega_s u'_{qr},$$
$$\frac{dE'_q}{dt} = -\frac{1}{T'_0}\left[E'_q - \left(X - X'\right) i_{ds}\right] - s\omega_s E'_d + \omega_s u'_{dr}. \quad (17)$$

Compared with (15) and (16), $(E'_q/\omega_s)(d\omega_s/dt)$ and $(E'_d/\omega_s)(d\omega_s/dt)$ are excluded in (17), which indicates that frequency is regarded as a constant in the third-order transient model of the asynchronous machine. However, this assumption will result in errors as frequency changes significantly.

4. Novel Simplified Asynchronous Machine Model

4.1. Variables and Parameters Redefinition. To represent the effect of frequency fluctuation and keep the simplicity of the third-order transient model of asynchronous machine, the variables and parameters should be redefined as follows:

$$\begin{gathered} E_d' = -\frac{L_m}{L_{rr}}\psi_{qr}, \qquad E_q' = \frac{L_m}{L_{rr}}\psi_{dr}, \\ L = L_{ss}, \qquad L' = L_{ss} - \frac{L_m^2}{L_{rr}}, \\ T_0' = \frac{L_{rr}}{R_r}, \\ u_{dr}' = \frac{L_m}{L_{rr}}u_{dr}, \qquad u_{qr}' = \frac{L_m}{L_{rr}}u_{qr}. \end{gathered} \tag{18}$$

Compared with (11), E_d' and E_q' have a linear relationship with flux linkage, whereby the angular frequencies ω_s, u_{dr}', and u_{qr}' are excluded.

4.2. Rotor Voltage Equations. From (12) and (18), the rotor voltage of the d component can be written as

$$\begin{aligned} u_{dr} &= R_r\left(\frac{\psi_{dr} - L_m i_{ds}}{L_{rr}}\right) + \frac{d\psi_{dr}}{dt} - (\omega_s - \omega_r)\psi_{qr} \\ &= \frac{1}{T_0'}\left(\frac{L_{rr}}{L_m}E_q' - L_m i_{ds}\right) + \frac{d}{dt}\left(\frac{L_{rr}}{L_m}E_q'\right) \\ &\quad + (\omega_s - \omega_r)\frac{L_{rr}}{L_m}E_d', \end{aligned} \tag{19}$$

where

$$\frac{d}{dt}\left(\frac{L_{rr}}{L_m}E_q'\right) = \frac{L_{rr}}{L_m}\left(\frac{dE_q'}{dt}\right). \tag{20}$$

Thus, (19) may be written as

$$\frac{dE_q'}{dt} = -\frac{1}{T_0'}\left[E_q' - \left(L - L'\right)i_{ds}\right] - s\omega_s E_d' + u_{dr}'. \tag{21}$$

Based on a similar principle, we can obtain the rotor voltage equation of the q component. The asynchronous machine transient model equations may then be rewritten as follows:

$$\begin{aligned} \frac{dE_d'}{dt} &= -\frac{1}{T_0'}\left[E_d' + \left(L - L'\right)i_{qs}\right] + s\omega_s E_q' - u_{qr}', \\ \frac{dE_q'}{dt} &= -\frac{1}{T_0'}\left[E_q' - \left(L - L'\right)i_{ds}\right] - s\omega_s E_d' + u_{dr}'. \end{aligned} \tag{22}$$

$d\omega_s/dt$ does not appear in the process of derivation, which indicates that frequency is not excluded in the novel simplified third-order transient model. With the new definition, E_d' and E_q' do not include angular frequency ω_s, and inductances L and L' are the parameters of the transient model, which can better reflect the physical characteristics of the asynchronous machine in the model.

4.3. Stator Voltage Equations. To reduce equations and make the model suitable for a stability program, we eliminate the rotor currents and express the relationship between stator current and voltage relative to a voltage behind the transient reactance. Thus, from (12) and (6), we obtain

$$\psi_{qs} = L_{ss}i_{qs} + L_m\left(\frac{\psi_{qr} - L_m i_{qs}}{L_{rr}}\right). \tag{23}$$

Substituting the above equation for ψ_{qs} in (4), the stator voltage equation of the d component may be rewritten as

$$\begin{aligned} u_{ds} &= R_s i_{ds} - \omega_s\left[L_{ss}i_{qs} + L_m\left(\frac{\psi_{qr} - L_m i_{qs}}{L_{rr}}\right)\right] \\ &= R_s i_{ds} - \omega_s\left[\left(L_{ss} - \frac{L_m^2}{L_{rr}}\right)i_{qs} - E_d'\right] \\ &= R_s i_{ds} - \omega_s L' i_{qs} + \omega_s E_d'. \end{aligned} \tag{24}$$

Similarly, we can obtain the d component of stator voltage equation, whereby the stator voltage equations may be written as

$$\begin{aligned} u_{ds} &= r_s i_{ds} - \omega_s L' i_{qs} + \omega_s E_d', \\ u_{qs} &= r_s i_{qs} + \omega_s L' i_{ds} + \omega_s E_q'. \end{aligned} \tag{25}$$

From (13) and (9), the electromagnetic torque equation can be expressed as

$$\begin{aligned} T_e &= \psi_{qr}i_{dr} - \psi_{dr}i_{qr} \\ &= \psi_{qr}\left(\frac{\psi_{dr} - L_m i_{ds}}{L_{rr}}\right) - \psi_{dr}\left(\frac{\psi_{qr} - L_m i_{qs}}{L_{rr}}\right) \\ &= E_d' i_{ds} + E_q' i_{qs}. \end{aligned} \tag{26}$$

4.4. Model Equations under System Reference Frame. The transient model equations should be transformed into public reference frame xy in system simulation. Figure 2 shows the relationship between reference frame xy and reference frame dq with a similar angular velocity ω_s in rad/s. φ is the angle by which the axis of x leads the axis of d in the direction of rotation. The transformation equation is

$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix}\begin{bmatrix} f_x \\ f_y \end{bmatrix}. \tag{27}$$

As a result, the transient model is obtained as follows.

Transient equations:

$$\begin{aligned} \frac{dE_x'}{dt} &= sfE_y' - u_{yr}' - \frac{1}{T_0'}\left[E_x' + \left(L - L'\right)i_{ys}\right], \\ \frac{dE_y'}{dt} &= -sfE_x' + u_{xr}' - \frac{1}{T_0'}\left[E_y' - \left(L - L'\right)i_{xs}\right]; \end{aligned} \tag{28}$$

stator voltage equations:

$$\begin{aligned} u_{xs} &= r_s i_{xs} - fL' i_{ys} + fE_x', \\ u_{ys} &= r_s i_{ys} + fL' i_{xs} + fE_y'; \end{aligned} \tag{29}$$

electromagnetic torque equation:

$$T_e = E'_x i_{xs} + E'_y i_{ys}; \quad (30)$$

rotor acceleration equation:

$$T_J \frac{ds}{dt} = sg(s_0)(T_m - T_e), \quad (31)$$

where $\omega_s = f$ per unit and s_0 is the initial slip of the asynchronous machine. If the asynchronous machine absorbs power, then $sg(s_0) = 1$; otherwise, $sg(s_0) = -1$ if the asynchronous machine produces power.

5. Model Analysis

Asynchronous machines are known to contain asynchronous induction motors and asynchronous generators; the difference between them lies in the acceleration and rotor voltage equations.

5.1. Asynchronous Induction Motor Model. An induction motor is a common asynchronous machine that converts electrical energy into mechanical energy based on the electromagnetic induction principle. The rotor voltage of the induction motor is zero $u'_{xr} = u'_{yr} = 0$, such that the novel simplified third-order transient model for the induction motor with consideration of the frequency characteristics is shown as follows.

Transient equations:

$$\begin{aligned} \frac{dE'_x}{dt} &= sfE'_y - \frac{1}{T'_0}\left[E'_x + (L - L')\, i_{ys}\right], \\ \frac{dE'_y}{dt} &= -sfE'_x - \frac{1}{T'_0}\left[E'_y - (L - L')\, i_{xs}\right]; \end{aligned} \quad (32)$$

acceleration equation:

$$T_J \frac{ds}{dt} = T_m - T_e; \quad (33)$$

stator voltage equations:

$$\begin{aligned} u_{xs} &= r_s i_{xs} - fL' i_{ys} + fE'_x, \\ u_{ys} &= r_s i_{ys} + fL' i_{xs} + fE'_y. \end{aligned} \quad (34)$$

5.2. Asynchronous Generator Model. Asynchronous generators are widely used in wind power generation. Most early wind generators are fixed-speed WT generators, and the induction generator operates at a constant speed. The use of variable speed constant frequency WT generators, such as the DFIG, is the mainstream in newly built wind farms. However, the models of different induction generators are similar, which may be written as follows.

Table 1: Wind generator parameters.

Para.	Value	Unit	Para.	Value	Unit
R_s	0.0092	pu	L_r	0.0717	pu
L_s	0.0717	pu	T_j	4	s
L_m	3.5	pu	f_n	60	Hz
R_r	0.007	pu	S_n	300	KVA

Table 2: Induction motor parameters.

Para.	Value	Unit	Para.	Value	Unit
R_s	0.016	pu	T_j	4	s
L_s	0.06	pu	f_n	60	Hz
L_m	3.5	pu	S_n	100	KVA
R_r	0.015	pu	v_n	10	m/s
L_r	0.06	pu			

Transient equations:

$$\begin{aligned} \frac{dE'_x}{dt} &= sfE'_y - u'_{yr} - \frac{1}{T'_0}\left[E'_x + (L - L')\, i_{ys}\right], \\ \frac{dE'_y}{dt} &= -sfE'_x + u'_{xr} - \frac{1}{T'_0}\left[E'_y - (L - L')\, i_{xs}\right]; \end{aligned} \quad (35)$$

acceleration equation:

$$T_J \frac{ds}{dt} = T_e - T_m; \quad (36)$$

stator voltage equations:

$$\begin{aligned} u_{xs} &= r_s i_{xs} - fL' i_{ys} + fE'_x, \\ u_{ys} &= r_s i_{ys} + fL' i_{xs} + fE'_y, \end{aligned} \quad (37)$$

where u'_{xr} and u'_{yr} are the equivalent rotor voltage with the following conditions: (1) for fixed-speed WT generators the rotor voltage $u'_{xr} = u'_{yr} = 0$ and (2) for variable speed constant frequency WT generators, which can supply rotor voltage through rotor side converter, the rotor voltage $u'_{xr} = u'_{yr} \neq 0$.

6. Simulation Analysis

A simplified power grid that contains composite load and wind generator, as shown in Figure 3, is built in Matlab/Simulink to test the performance of the novel simplified asynchronous machine model with consideration of frequency characteristics. Tables 1 and 2 list the parameters of this simulation system. The power grid is an isolated power system with a 300 kW capacity. The load of this power grid comprises static load (ZIP) and asynchronous induction motor, which consume the total power output from the wind generator during normal operation. A synchronous generator is used as a phase converter to maintain system voltage. The capacitors with 75 kvar total capacity are used to supply reactive power.

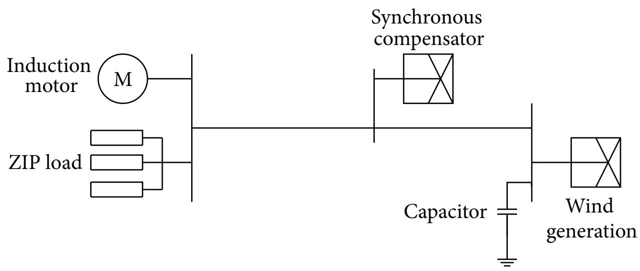

Figure 3: Simulation system.

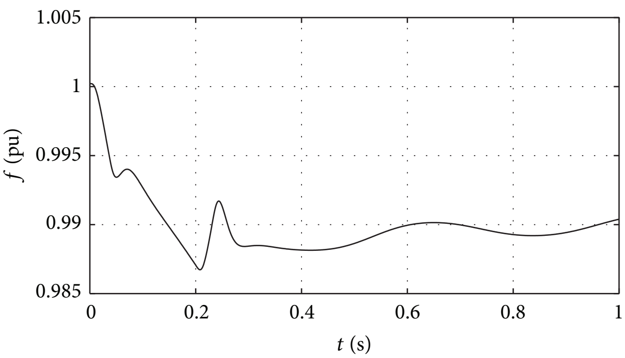

Figure 4: System frequency.

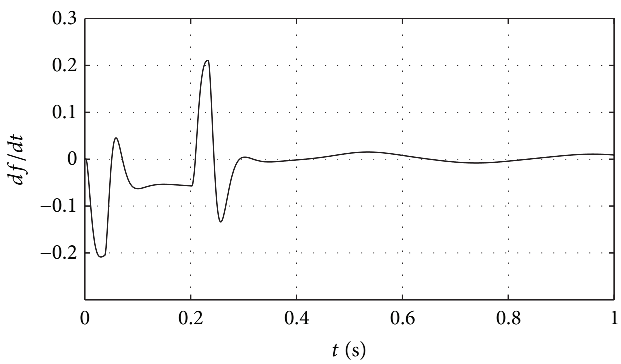

Figure 5: df/dt.

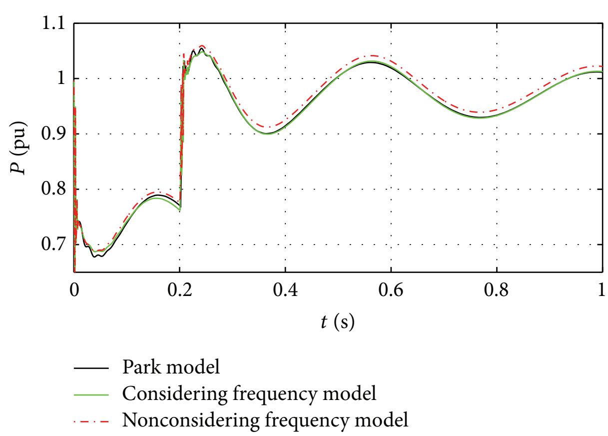

Figure 6: The active power of induction motor.

Table 3: Error analysis of different models.

Machine type	Relative error	
	Active power	Reactive power
Induction motor		
Traditional simplified model	0.00962	0.020067
Novel simplified model	0.000134	0.01213
Wind generator		
Traditional simplified model	0.02963	0.0314542
Novel simplified model	0.02076	0.0306382

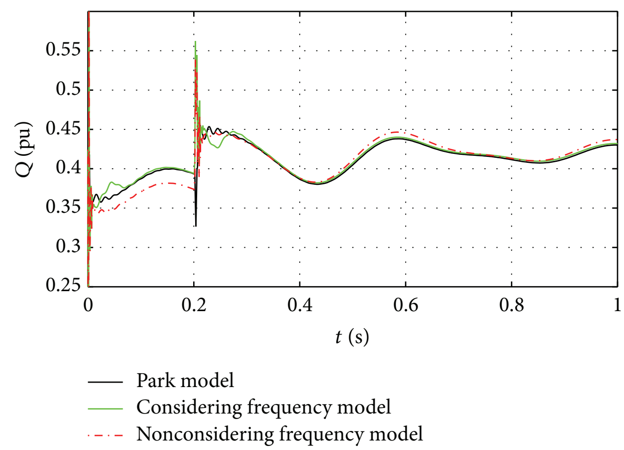

Figure 7: Reactive power of induction motor.

The responses of the novel simplified third-order transient model of the asynchronous machine (both induction motor and wind generator) under a decrease in wind speed and electrical load fault are studied. During the disturbance, the output power of wind generator is fluctuate, as well as the consume power of motor machine. Power system will recover stability when the disturbance is clear. It cannot come to opposite conclusions with the two models.

6.1. Case A. In the first case, the initial load is assumed to be 200 kW, which increases suddenly to 300 kW in approximately 0.2 s, thereafter returning to 200 kW. Figure 4 shows that the system frequency decreases in response to the sudden increase in load and the derivative of frequency is shown in Figure 5. Subsequently, the system reaches a new stable operating point, and the frequency recovers slowly after an obvious fluctuation.

Figures 6, 7, 8, and 9 show a comparison between the output active and reactive power of the traditional simplified third-order transient model, novel simplified third-order transient model, and detailed Park model of induction motor and wind generator. As the load increases, the wind generator produces more active power and absorbs more reactive power. The output power of the novel simplified third-order transient model with consideration of the frequency is shown to be more accurate than that of the traditional simplified third-order transient model and almost matches that of the Park model.

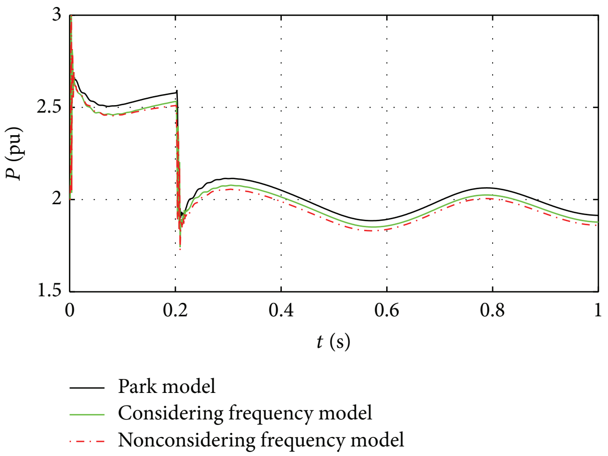

Figure 8: Active power of wind generator.

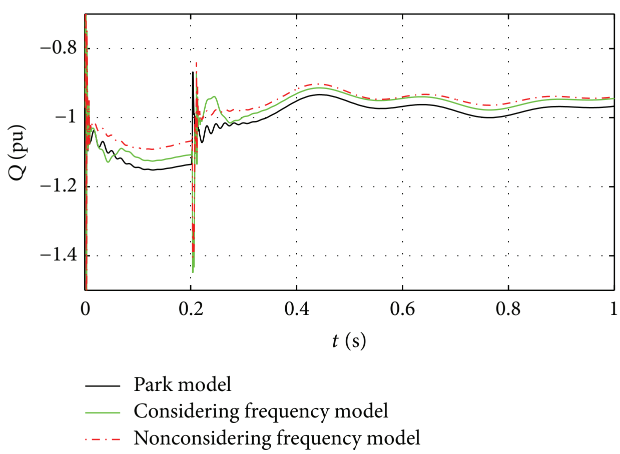

Figure 9: Reactive power of wind generator.

Table 3 shows the accumulated errors between the traditional simplified third-order transient model and novel simplified third-order transient model compared with the detailed model (Park model). The error between the novel simplified transient model with consideration of the frequency and the detailed model is shown to be less than that between the traditional simplified transient model and the detailed model.

6.2. Case B. A wind speed disturbance is used to analyze the effect of frequency in the second case. To highlight the frequency fluctuation as a result of wind speed change, an assumed wind condition is used with a 10 m/s initial wind speed, which drops to 7 m/s and recovers to 10 m/s in 0.2 s, as shown in Figure 10. Figure 14 shows the output power of a WT generator. The figure also shows that the generated wind power decreases in response to the decrease in wind speed and the active power of the induction motor absorbed the decrease with a drop in voltage. Figure 11 shows that the system frequency decreases rapidly because of the unbalanced generation of active power and load and recovers slowly when the wind speed returns to 10 m/s.

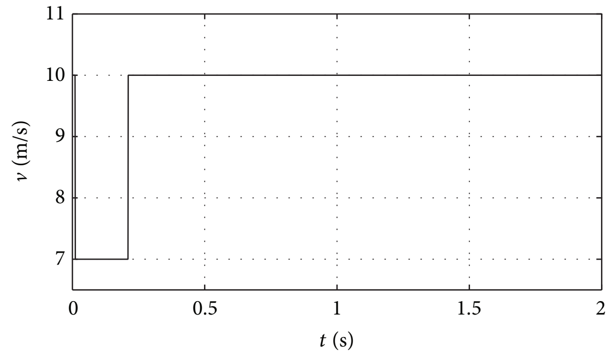

Figure 10: Wind speed variable.

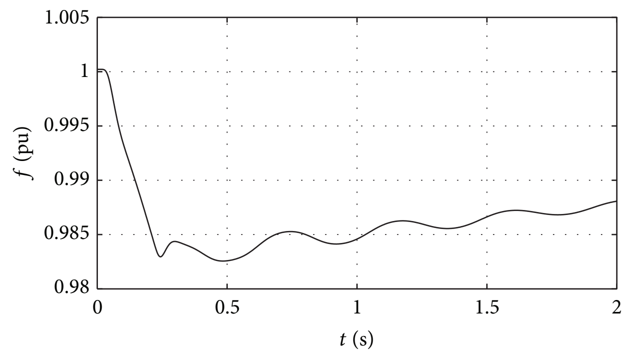

Figure 11: System frequency.

Table 4: Error analysis of different models.

Machine type	Relative error: Active power	Relative error: Reactive power
Induction motor		
Traditional simplified model	0.016065	0.02318
Novel simplified model	0.003851	0.006983
Wind generator		
Traditional simplified model	0.027847	0.044735
Novel simplified model	0.009233	0.02119

Figures 12 to 15 show the comparison between the output active and reactive power of the traditional third-order transient model, novel simplified third-order transient model with consideration of the frequency, and detailed Park model of induction motor and wind generator. In the novel simplified third-order transient model with consideration of the frequency, the output of the induction motor and wind generator can better track the output of the detailed model (Park model). The active power error is less than the reactive power error (see Figures 13 and 15).

Table 4 shows that the accumulated error of active power and reactive power between the novel simplified third-order transient model (both induction motor and wind generator) and Park model is less.

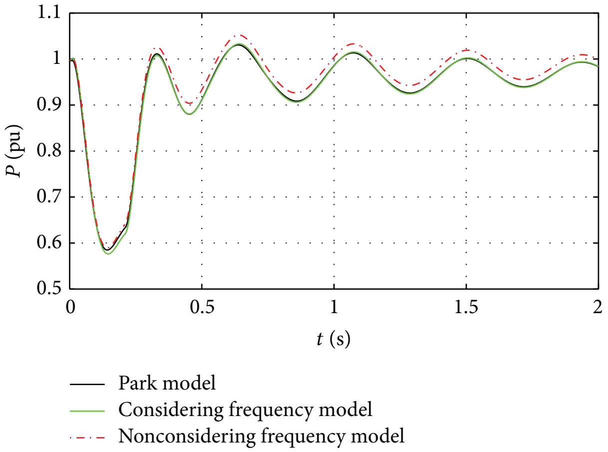

FIGURE 12: Active power of induction motor.

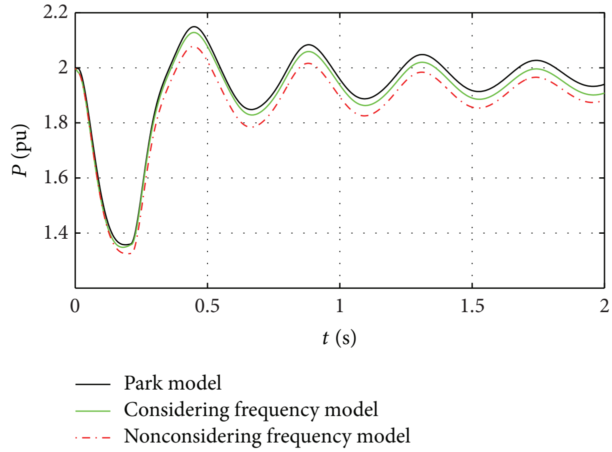

FIGURE 14: Active power of wind generator.

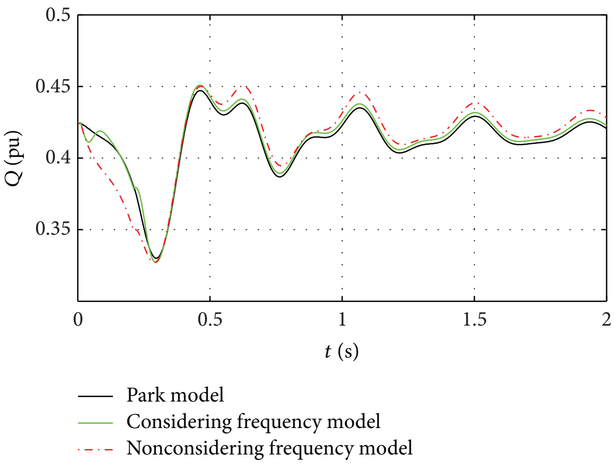

FIGURE 13: Reactive power of induction motor.

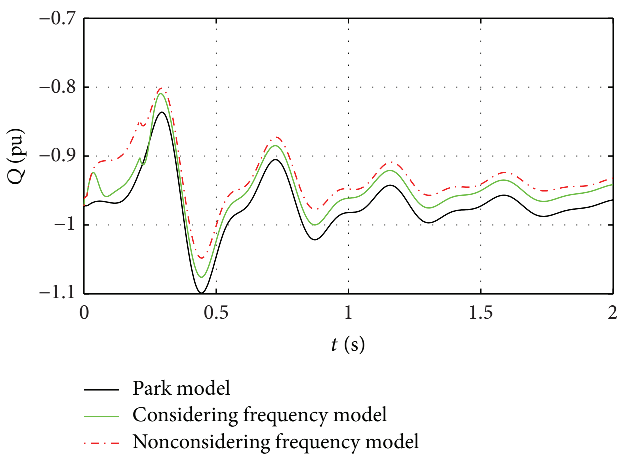

FIGURE 15: Reactive power of wind generator.

7. Conclusions

A novel simplified third-order transient model with consideration of the frequency characteristics of an asynchronous machine is proposed in this paper. The new model focuses on the effects of frequency fluctuation on the power system dynamics. In the new definitions of variables, the voltages behind the reactance are redefined as the linear equation of flux linkage. As a result, the rotor voltage equation is not associated with the derivative terms of frequency. The novel transient model is applicable to the simulation of the power system dynamic with a significant change in frequency. Simulation results verify that the novel simplified third-order transient model is effective and can describe more accurately the dynamics of an asynchronous machine in contrast to the traditional simplified third-order transient model.

Conflict of Interests

The authors declare that there is no conflict of interests.

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