Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 9 (2023) 662–669
www.elsevier.com/locate/egyr

2022 9th International Conference on Power and Energy Systems Engineering (CPESE 2022), Doshisha University, Kyoto, Japan, 9–11 September 2022

Synthetic load modelling considering the influence of distributed generation☆

Qi Wang[a,*], Bing Zhao[a], Bixing Ren[b], Qiang Li[b], Jie Hao[a], Tiankai Lan[a], Pandeng Luo[a]

[a] *China Electric Power Research Institute, Haidian District, Beijing 100192, China*
[b] *State Grid Jiangsu Electric Power Company Ltd. Research Institute, Nanjing 211103, China*

Received 23 October 2022; accepted 2 November 2022
Available online xxxx

Abstract

In order to establish a load model with distributed generation which is suitable for large-scale power system transient simulation under the background of high permeability of new energy, firstly a four machine integrated load model structure that describes the mixing of distributed new energy and traditional load is constructed in this paper, then a reduced order equivalent algorithm for distributed new energy clusters is proposed to determine the parameters of the distributed power equivalent model. Finally, an example is given to verify the effectiveness of the proposed method. The simulation results verify that the proposed method can accurately simulate the comprehensive load characteristics of distribution network with distributed generation.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Power and Energy Systems Engineering, CPESE, 2022.

Keywords: Distributed photovoltaic power generator; Doubly-fed induction generator (DFIG); Permanent magnetic synchronous generator (PMSG); Distributed renewable energy generator (DREG); Load model; Low voltage ride-through (LVRT)

1. Introduction

With the World's energy infrastructure transformation to clean, low-carbon, safe and efficient, the development of China's energy and power system is facing critical strategic opportunity, with quickly developing energy supply and demand. Recently, the new energy including wind and PV has been developed very fast in China. In the end of 2021, China's power supply has been installed 2.38 billion kW, in which the installation capacity of non-fossil energy power generation reached 1.12 billion kW. It is the first time the installation capacity of non-fossil energy is more than that of coal energy. The installation capacity of Water, Wind and PV energy have been reached 390

☆ Project Supported by Science and Technology Project of State Grid Corporation of China: Research on Refined Modelling and Simulation Technology of High Permeability Distributed Generation Connected to Power Grid (5100-202155428A-0-0-00).
* Corresponding author.
E-mail address: wangqi@epri.sgcc.com.cn (Q. Wang).

https://doi.org/10.1016/j.egyr.2022.11.036

Peer-review under responsibility of the scientific committee of the 9th International Conference on Power and Energy Systems Engineering, CPESE, 2022.

million kW, 330 million kW, 310 million kW, which are all the No. 1 in the world. The renewable energy generation is becoming primary power source from auxiliary source.

Due to the highly dynamic in multiple time scales, with enormous switch and control operation of power electronic devices, it is very difficult to precisely and efficiently modelling the simulation of power system with high proportion of new energy. It is also a great challenge to cognition of power system stability evolution. For more details, the parameters of power electronics devices are mainly determined by the control and protection logic. It is complicated to model the single device, and the parameters of enormous power electronics devices are difficult to converge and equivalent on the source side and load side. The conventional multiply-capacity method to determine the device cluster parameters, is simple with no good accuracy. Accurate modelling the device cluster according to the practical topology faces the problem of huge simulation scale and low computation speed, which is not applicable in the large power system simulation. For the large power system simulation, it is necessary to improve the mechanic and electric modelling method for power electronic devices/cluster. On the other side, the load characteristic of large power system simulation is greatly changed with many distributed power sources installed in low-voltage grid. But the impact between distributed power generation and large power grid is still not clear. Usually the distributed generation is considered as part of power load in the large power system analysis, which is not accurate for fused equivalent of enormous distributed generation in the main grid level. It is difficult consider the control protection response characteristics of distributed generation in the case of large disturbance in main power grid, and it is highly impaired the power grid simulation accuracy considering high-proportion installed distributed generation. Thus it is urgent to research the load modelling technique considering distributed generation, in order to provide strong technique support for safe installation and efficient utilization of power electronics devices including high proportion new energy sources, and support the safe and stable operation of high proportion new energy power system in China.

There have been some research works focusing on load modelling, including statistics synthesis method [1–5], parameter identification method [6,7], fault fitting method [8–10], etc. But there are a few researches considering load modelling of distributed new energy [11–17]. The work [11] focused on static equivalent value of distributed PV generation system widely installed in distribution power grid, in which the equivalent model includes loads of static constant-resistance, constant-current and constant-power, and PV station model, but the dynamic characteristics of distributed PV generation system have not been considered. The work [12] added an equivalent PV station based on synthesis load model, then chose important parameters via track sensitivity method, finally identify the key parameters. Neither it did not consider the detailed dynamic characteristics during the low voltage ride through of distributed PV generation system, which is critical to power grid stability [13], thus the control parameters of equivalent generator during low voltage ride through period should be focused. In work [14], the equivalent control parameters of PV generator was calculated by taking the total active power of distributed PV generators in the whole 220 kV substation as the weight coefficient, because the voltage differences of the grid connection points of DREGs were not considered, which may lead to a large difference between the response characteristics of the aggregated equivalent system in some scenarios and the response characteristics of the actual detailed system.

In order to establish a load model with distributed generation which is suitable for large-scale power system transient simulation under the background of high permeability of new energy, firstly a four machine integrated load model structure that describes the mixing of DERGs and traditional load is constructed in this paper, then a reduced order equivalent algorithm for distributed new energy clusters is proposed to determine the parameters of the distributed power equivalent model, this method takes into account the voltage difference of the grid connection points of DREGs and the network losses caused by the transient outputs of DREGs flowing through the distribution grid. Finally, an example is given to verify the effectiveness of the proposed method. The simulation results verify that the proposed method can accurately simulate the comprehensive load characteristics of distribution network with distributed generation.

2. Load model considering DREG

2.1. The synthesis load model with DREG

The proposed a four machine integrated load model structure that describes the mixing of DERGs and traditional load is shown in Fig. 1, which consists of distribution equivalent resistance ($R_D + jX_D$), constant resistance load(Z), constant current load(I), constant power load(P), induction motor(M), doubly-fed induction generator

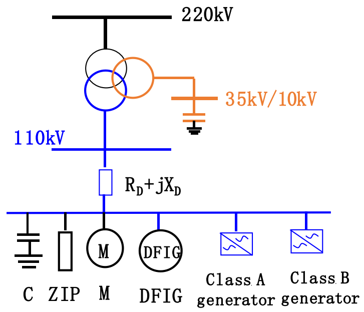


Fig. 1. Integrated load model structure.

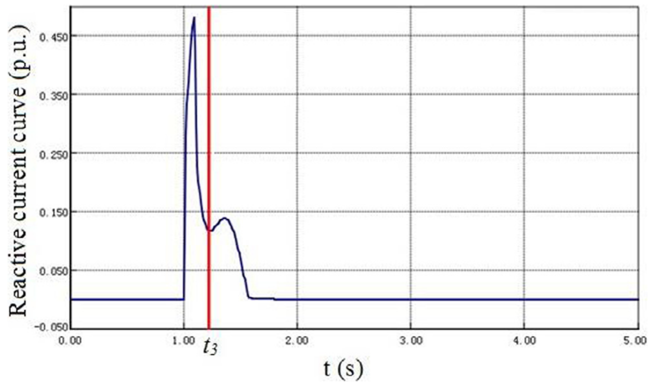


Fig. 2. Reactive current of generator considering LVRT characteristics.

(DFIG), class A DREG considering fault ride through characteristics (including photovoltaic generator and permanent magnetic synchronous generator), class B DREG without considering fault ride through characteristics (including photovoltaic generator and permanent magnetic synchronous generator), compensate capacitor(C). The parameters should be calculated in distribution load area with distributed generation equivalent modelling include: distribution grid equivalent resistance; the installation capacity, the maximum active power, the practical active power, inverter control parameters of DFIG; the installation capacity, the maximum active power, the practical active power, inverter control parameters of class A equivalent DREG; the installation capacity, the maximum active power, the practical active power, inverter control parameters of class B equivalent DREG; the active power and reactive power of equivalent load; equivalent reactive power compensation, etc.

3. Load model parameter computation with DREG

In accordance with the synthesis load model structure with DREG in previous section, the load model with DREG consists of seven parts: distribution grid equivalent impedance, equivalent DFIG, equivalent class A generator, equivalent class B generator, reactive power compensation, equivalent static load, equivalent motor load. For the last three parameters, the equivalent computation method has been proposed in [15–17], which will not be repeated in this paper. In this section, the computation method will be introduced for distribution grid equivalent impedance, equivalent DFIG, equivalent class A generator, equivalent class B generator.

3.1. The computation method of distribution grid equivalent resistance

Since the power consumed by distribution grid resistance is equal to the power consumption sum of each transformer and each power line in the distribution grid, the distribution grid equivalent impedance is calculated as,

$$R_D + \mathrm{j}X_D = \left[\sum_{j=1}^{l}\left(\frac{P_j^2+Q_j^2}{U_j^2}\right)\vec{Z}_j\right] / \left(\sum_{i=1}^{k} I_{Li}\right)^2 \tag{1}$$

where, R_D and X_D represent the distribution grid equivalent resistance and reactance respectively; P_j and Q_j represent the active power and reactive power of the j_{th} transformer/power-line, U_j is the bus voltage of the j_{th} transformer/power-line, Z_j is the impedance of j_{th} transformer/power-line; I_{Li} is the current of i_{th} load.

3.2. The computation method of model parameters of equivalent DREGs

The class A generator is used as an example to illustrate the computation method.

(1) The computation of rated capacity S_{NEQ} of class A generator is

$$S_{NEQ} = \sum_{i=1}^{\mathrm{m}} S_{Ni} \tag{2}$$

where S_{Ni} is the rated capacity of the i_{th} class A generator, m is the number of class A generators.

(2) The computation of maximum reactive power capacity Q_{NEQ} of class A generator is

$$Q_{NEQ} = \sum_{i=1}^{\mathrm{m}} Q_{Ni} \tag{3}$$

where Q_{Ni} is the maximum reactive power capacity of the i_{th} class A generator.

(3) The computation of active power output P_{AEQ} of class A equivalent distributed generator is

$$P_{AEQ} = \sum_{i=1}^{\mathrm{m}} P_{Ai} \tag{4}$$

where P_{Ai} is the active power output of the $\mathrm{i_{th}}$ class A distributed generator.

(4) Computation of active current control parameters during LVRT period

When the active current control mode during LVRT process is constant current control mode, the control strategy is demonstrated as following:

$$I_{PLVRT} = K_{1\_Ip\_LV} * V_t + K_{2\_Ip\_LV} * I_{p0} + I_{pset\_LV} \tag{5}$$

where, $K_{1\_Ip\_LV}$ is the calculation coefficient 1 of active current, $K_{2\_Ip\_LV}$ is the calculation coefficient 2 of active current, I_{pset_LV} is the calculation coefficient 3 of active current, I_{p0} is the initial active current of generator, and V_t is the terminal voltage.

Thus the control parameters of class A generator are calculated as following:

(1) Calculate the active current coefficient 3 $I_{pset\_LV\_EQ}$ of the equivalent generator as Eq. (6).

$$I_{pset\_LV\_EQ} = \sum_{i=1}^{m}\left(\frac{S_{Ni}}{S_{NEQ}}\right) * \frac{1}{(T_{1i} * T_{2i})} * I_{pset\_LVi} \tag{6}$$

where, T_{1i} is the convert ratio of grid-connected transformer of the $\mathrm{i_{th}}$ generator, T_{2i} is the convert ratio of transformer lifting the voltage to 110 kV level.

(2) From the simulated active current curves of each generator, the initial active current I'_{p0i} of generator i is obtained; the active current $I'_{pt1,i}$, the 220 kV side voltage $V_{220,\mathrm{t1}}$ of 220 kV transformer, the active power $P_{220,\mathrm{t1}}$ and reactive power $Q_{220,\mathrm{t1}}$ flowing through 220 kV side of 220 kV transformer at fault clearance time t_1 are also obtained; also read the active current $I'_{pt2,i}$ of generator i, the 220 kV side voltage $V_{220,\mathrm{t2}}$ of 220 kV transformer, the active power $P_{220,\mathrm{t2}}$ and reactive power $Q_{220,\mathrm{t2}}$ flowing through 220 kV side of 220 kV transformer, at time t_2 when the sum of active currents of all class A generators arrives the maximum value.

(3) Calculate the initial active power current I'_{p0EQ} of equivalent system with Eq. (7).

$$I'_{p0EQ} = \sum_{i=1}^{m} I'_{p0i} / (T_{1i} * T_{2i}) \tag{7}$$

(4) Calculate the sum of currents of each generator i at 110 kV side of 220 kV transformer at time t_1, as show in Eq. (8).

$$I'_{pt1} = \sum_{i=1}^{m} I'_{pt1,i} / (T_{1i} * T_{2i}) \tag{8}$$

(5) Calculate the sum of currents of each generator i at 110 kV side of 220 kV transformer at time t_2, as show in Eq. (9).

$$I'_{pt2} = \sum_{i=1}^{m} I'_{pt2,i} / (T_{1i} * T_{2i}) \tag{9}$$

(6) At time t_1, the equivalent generator's active power current should be equal with the active power current at the 110 kV side of 220 kV transformer, i.e.,

$$I'_{PLVRTEQ,\ t1} = I'_{pt1} \tag{10}$$

(7) At time t_2, the equivalent generator's active power current should be equal with the active power current at the 110 kV side of 220 kV transformer, i.e.,

$$I'_{PLVRTEQ,\ t2} = I'_{pt2} \tag{11}$$

(8) Calculate the $V_{EQ,t1}$ and $V_{EQ,t2}$at time t_1 and t_2 with Eq. (12), and substitute the values into Eq. (5). From Eqs. (5)–(11), the factor one of active power current computation $K_{1\_Ip\_LV\_EQ}$ can be solved with Eq. (13); while the factor two of active power current computation $K_{2\_Ip\_LV\_EQ}$ can be solved with Eq. (14).

$$\left|\dot{V}_{EQ,t}\right| = \sqrt{U_{1,t}^2 + \frac{X^2}{U_{1,t}^2}\left(P_{1,t}^2 + Q_{1,t}^2\right) - 2XQ_{1,t}} \tag{12}$$

$$K_{1\_Ip\_LV\_EQ} = \frac{S_b}{S_{NEQ}} * \frac{\left(I'_{PLVRTEQ,\ t1} - I'_{PLVRTEQ,\ t2}\right)}{\left(V_{EQ,t1} - V_{EQ,t2}\right)} \tag{13}$$

$$K_{2\_Ip\_LV\_EQ} = \frac{\left(I'_{pt1} - K_{1\_Ip\_LV\_EQ} * V_{EQ,t1} * \frac{S_{NEQ}}{S_b} - I_{Pset\_LV\_EQ} * \frac{S_{NEQ}}{S_b}\right)}{I'_{p0EQ}} \tag{14}$$

where $U_{1,t}$ is the 220 kV side voltage of 220 kV transformer, $P_{1,t}$ is the ingress active power on 220 kV side, $Q_{1,t}$ is the ingress reactive power on 220 kV side, X is equal to the sum of distribution grid equivalent reactance and 220 kV transformer high-middle voltage side reactance.

(3) Computation of reactive power current control parameter during LVRT period

When the reactive current control mode of new energy generator during low voltage ride through is the specified constant current control mode, the reactive current of photovoltaic generator during low voltage ride through I_{qLVRT} is:

$$I_{qLVRT} = K_{1\_Iq\_LV} * (V_{Lin} - V_t) + K_{2\_Iq\_LV} * I_{q0} + I_{q_{set\_LV}} \tag{15}$$

where $K_{1\_Iq\_LV}$ is the calculation coefficient 1 of reactive current, $K_{2\_Iq\_LV}$ is the calculation coefficient 2 of reactive current, I_{qset_LV} is the calculation coefficient 3 of reactive current, I_{q0} is the initial reactive current, V_t is the terminal voltage of generator, V_{Lin} is the threshold voltage for generator to enter low voltage ride through process.

The reactive power current control parameters are calculated as below.

(1) Since I_{q_0} is zero, $K_{2\_Iq\_LV\_EQ}$ has no impact, thus it can be set to 1.

(2) From the simulated reactive current curve of each generator, the reactive current $I'_{qt1,i}$ of generator i, the 220 kV side voltage $V_{220,t1}$ of 220 kV transformer, the active power $P_{220,t1}$ and reactive power $Q_{220,t1}$ flowing through 220 kV side of 220 kV transformer at fault clearance time t_1 are obtained; also read the 220 kV side voltage $V_{220,t3}$ of 220 kV transformer, the active power $P_{220,t3}$ and reactive power $Q_{220,t3}$ flowing through 220 kV side of 220 kV transformer at time t_3 when the first knee point of the sum of reactive currents of all class A generators, as shown in Fig. 2.

(3) Calculate the sum of reactive current I'_{qt1} of each generator i at 110 kV side of 220 kV transformer at time t_1, as show in Eq. (16).

$$I'_{qt1} = \sum_{i=1}^{m} I'_{qt1,i} / (T_{1i} * T_{2i}) \tag{16}$$

(4) Calculate the sum of reactive power currents I'_{qt3} of each generator i at 110 kV side of 220 kV transformer at time t_3, as show in Eq. (17).

$$I'_{qt3} = \sum_{i=1}^{m} I'_{qt3,i} / (T_{1i} * T_{2i}) \tag{17}$$

(5) At time t_1, the equivalent generator's reactive current should be equal with the reactive current at the 110 kV side of 220 kV transformer, i.e.

$$I'_{qLVRTEQ,\ t1} = I'_{qt1} \tag{18}$$

(6) At time t_3, the equivalent generator's reactive current should be equal with the reactive current at the 110 kV side of 220 kV transformer, i.e.:

$$I'_{qLVRTEQ,\ t3} = I'_{qt3} \tag{19}$$

(7) Calculate the $V_{EQ,t1}$ and $V_{EQ,t3}$at time t_1 and t_3 by using Eq. (12), thus the factor 1 of reactive power current computation $K_{1\_Iq\_LV\_EQ}$ can be solved with Eq. (20); while the factor 2 of reactive power current computation $K_{2\_Iq\_LV\_EQ}$ can be solved with Eq. (21).

$$K_{1\_Iq\_LV\_EQ} = \frac{S_b}{S_{NEQ}} * \frac{\left(I'_{qLVRTEQ,\ t1} - I'_{qLVRTEQ,\ t3}\right)}{\left(V_{EQ,t3} - V_{EQ,t1}\right)} \tag{20}$$

$$I_{q_{set}\_LV\_EQ} = \frac{S_b}{S_{NEQ}} * I'_{qLVRTEQ,\ t1} - K_{1\_Iq\_LV\_EQ} * \left(V_{Lin,EQ} - V_{EQ,t1}\right) \tag{21}$$

where $V_{Lin,EQ} = \min\left(V_{Lin,i}\right)$ °

(8) Optimization of reactive current control coefficient 3 I_{qset_LV} with the correction generated by active power

In the detailed system, the active current introduces additional reactive power consumption in grid. The consumption is less in the equivalent system. The reactive power output of distributed generation should be reduced to compensate the less part of reactive power consumption.

$$\sum_{i=1}^{m} {I'_{pi}}^2 * X_i = \Delta I'_q * V_{tEQ} \tag{22}$$

where I'_{pi} is the active current of the i_{th} generator, X_i is the reactance between the i_{th} generator and 110 kV side bus of 220 kV transformer, $\Delta I'_q$ is the reduced reactive current of equivalent generator.

From Eq. (22), we have

$$\Delta I'_q = \frac{\sum_{i=1}^{m} {I'_{pi}}^2 * X_i}{V_{tEQ}} \tag{23}$$

To ensure the recovery conservatism of equivalent system, the calculation process chooses the current value when the sum of active currents of all generators becomes the maximum.

Convert $\Delta I_q'$ to ΔI_q based on equivalent generator capacity,

$$\Delta I_q = \Delta I_q' * \frac{S_b}{S_{NEQ}} \tag{24}$$

Thus $I_{q_{set\_LV\_EQ}}$ should be modified to $I_{q_{set\_LV\_EQ}}$ from Eq. (21) minus ΔI_q from Eq. (24).

$$I_{q_{set\_LV\_EQ,f}} = I_{q_{set\_LV\_EQ}} - \Delta I_q \tag{25}$$

4. Case study

To validate the effectiveness of proposed load modelling method considering DREG, the 220 kV substation A is used as an example to analyse. The 220 kV substation A has 14 DREGs, including 2 class B PV generators, 2 DFIGs, 10 class A distributed PV generators. The parameters of all DREGs and the control parameters of all generators are listed in [13]. According to the detailed data of DREG in substation A, the equivalent control model parameters of class A PV and DFIGs during the LVRT in substation A are calculated with the proposed method as shown in [13].

The simulation system is shown in Fig. 3: Generator G1 and G2 supply power to substation A through three-circuit line and one-circuit line respectively. The original detailed system of 220 kV substation A and the equivalent load model with DREGs are connected to Bus 6 respectively for simulation.

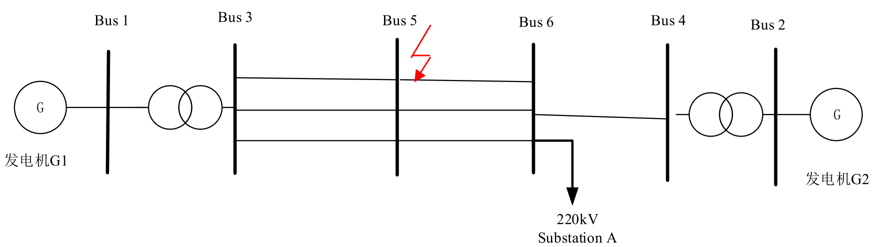
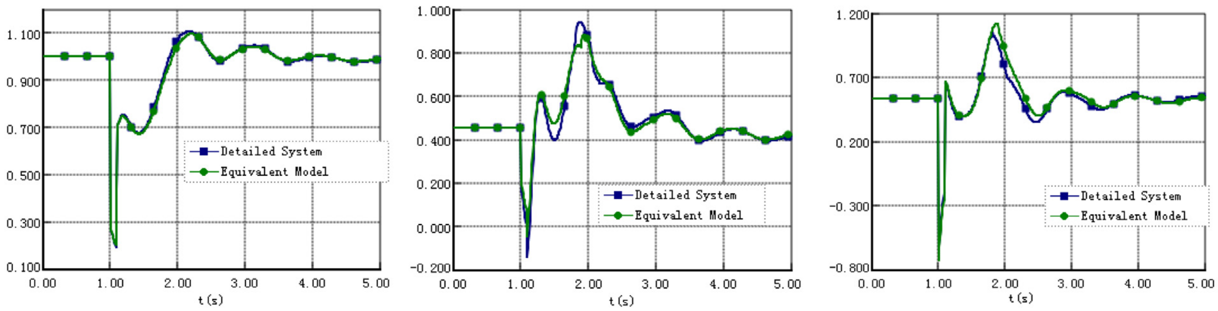


Fig. 3. Schematic diagram of simulation system.

Simulation conditions are: a three-phase permanent N-1 fault is occurred at Bus 5 side of Bus 5-Bus 6 line, 0.09 s after the fault the line proximal is cut, and 0.1 s after the fault the line distal is cut.

The simulation results are shown in Fig. 4. It can be seen from Fig. 4 that the 220 kV bus voltage of substation A, the down-grid active power of substation A and the down-grid reactive power of substation A under the two models all fit perfectly. The simulation results show that the maximum voltage difference of 220 kV bus is less than 0.03 p u., thus means the equating error is less than 3%. In conclusion, it can be seen that the equivalent load model with DREG can simulate the active and reactive characteristics of the original detail system very well. This verifies the effectiveness of the proposed load modelling method.



(a) 220kV bus voltage of substation A; (b) Down-grid active power of substation A; (c) Down-grid reactive power of substation A;

Fig. 4. Simulation results of detailed system and equivalent model.

5. Conclusions

Firstly, this paper has constructed a four machine integrated load model structure that describes the mixing of distributed new energy and traditional load, then a reduced order equivalent algorithm for distributed new energy clusters has been proposed to determine the parameters of the distributed power equivalent model., this method takes into account the voltage differences of the grid connection points of DREGs and the network losses caused by the transient outputs of DREGs flowing through the distribution grid. Simulation results show that the maximum voltage difference of 220 kV bus is less than 3%, which means that the proposed method can realize the accurate simulation of the actual dynamic characteristics of tens of thousands of DREGs in the power grid with an equivalent renewable energy generator, and greatly improves the accuracy of power system simulation calculation, At the same time, it greatly improves the speed and efficiency of power system simulation, and provides strong support for high-precision simulation of power grid and safe decision-making of production and operation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

References

[1] Zhu Jizhong. IEEE draft guide for load modeling and simulations for power systems. In: IEEE std 2781-2022. 2022.
[2] IEEE task force on load representation for dynamic performance, load representation for dynamic performance analysis. IEEE Trans Power Syst 1993;8(2):472–82.
[3] Qi W, Jun Y, Bing Z, Liping L, Yong T. Deepen research on electric load modelling. In: 2015 5th international conference on electric utility deregulation and restructuring and power technologies. DRPT, 2015, p. 334–9.
[4] Hiskens IA, Milanovic JV. Load modeling in studies of power system damping. IEEE Trans Power Syst 1995;10(4):1781–6.
[5] Ju Ping, Qin Chuan, Wu Feng, et al. Load modeling for wide area power system. Int J Electr Power Energy Syst 2011;(4).
[6] Frigo G, Derviškadić A, Colangelo D, et al. Characterization of uncertainty contributions in a high-accuracy PMU validation system. Measurement 2019;146.
[7] Bashian Amir, Assili Mohsen, Anvari-Moghaddam Amjad, et al. Co-optimal PMU and communication system placement using hybrid wireless sensors. Sustain Energy Grids Netw 2019;19.
[8] Walve K. Modeling of power system components at severe disturbances. CIGRE paper, 1986, p. 38–18.
[9] Alam Mehebub, Kundu Shubhrajyoti, Thakur Siddhartha Sankar, et al. PMU based line outage identification using comparison of current phasor measurement technique. Int J Electr Power Energy Syst 2020;115.
[10] Milanovic JV, Yamashita K, Villanueva SM, et al. International industry practice on power system load modeling. IEEE Trans Power Syst 2013;28(3):3038–46.
[11] Samadi A, Soder L, Shayesteh E, et al. Static equivalent of distribution grids with high penetration of PV systems. IEEE Trans Smart Grid 2015;6(4):1–12.
[12] Feng WU, Wei LI. Dynamic equivalence analysis of distribution network integrated with high-penetration distributed photovoltaic generation system. Autom Electr Power Syst 2017;41(9):65–70, 181.
[13] Wang Qi, Cao Lu, Li Jianhua, et al. Research on the influence of load model with distributed pv generation on the voltage stability of receiving-end power grid. China Electric Power Research Institute; 2022.
[14] Chao P, Li W, Peng S, Liang X, Zhang L, Shuai Y. Fault ride through behaviors correction-based single-unit equivalent method for large photovoltaic power plants. IEEE Trans Sustain Energy 2021;12(1):715–26.
[15] Qi W, Bing Z, Lingkuan W. Summary of load modeling methods considering distributed generation. In: 2019 IEEE 3th conference on energy internet and energy system integration (EI2). 2019, p. 1986–90.
[16] Qi W, Bing Z, Huadong S. Research on load modeling considering distributed photovoltaic generation. In: 2020 IEEE 4th conference on energy internet and energy system integration (EI2). 2020, p. 1407–12.
[17] Li P, et al. High-precision dynamic modeling of two-staged photovoltaic power station clusters. IEEE Trans Power Syst 2019;34(6):4393–407.