Model validation of solar PV plant with hybrid data dynamic simulation based on fast-responding generator method

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Abstract. In recent years, a significant number of large-scale solar photovoltaic (PV) plants have been put into operation or been under planning around the world. The model accuracy of solar PV plant is the key factor to investigate the mutual influences between solar PV plants and a power grid. However, this problem has not been well solved, especially in how to apply the real measurements to validate the models of the solar PV plants. Taking fast-responding generator method as an example, this paper presents a model validation methodology for solar PV plant via the hybrid data dynamic simulation. First, the implementation scheme of hybrid data dynamic simulation suitable for DIgSILENT PowerFactory software is proposed, and then an analysis model of solar PV plant integration based on IEEE 9 system is established. At last, model validation of solar PV plant is achieved by employing hybrid data dynamic simulation. The results illustrate the effectiveness of the proposed method in solar PV plant model validation.

1 Introduction

With the rapid increase of solar photovoltaic (PV) power integration, its impact on the power grid has received extensive concern and excited wide research interests [1]. The model accuracy of solar PV is the key factor to investigate the mutual influences between it and a power grid. However, this problem has not been well solved. Currently, most research of solar PV model validation is concentrated in solar PV inverter and solar PV unit, and is not enough for solar PV plant or plants.

In recent years, with the wide application of PMU (phasor measurement unit) and WAMS (wide-area measurement system), hybrid data dynamic simulation method is proposed and has been successfully applied in synchronous generator model validation, load model validation, and so on [2-4]. Hybrid data dynamic simulation injects external signals to simulation process and opens traditional dynamic simulation loops for interaction with external signals. It is "hybrid" in the sense of bridging the measurement world with the simulation world [3]. Typical data dynamic simulation techniques consist of fast-responding generator method [2-3], phase shifter method [3], variable impedance method [4] and the ideal voltage source method. Among these methods, the fast-responding generator method injects bus voltage and frequency, and it does not require the phase-angle data (for solar PV plants, rare PMU is installed), so it is more suitable for solar PV plant model validation. However, according to the existing literatures, the implementation details of fast-responding generator method and its application in the model validation of renewable energy power plants are all disclosed, this paper will investigate these problems.

2 Modeling of solar PV plant grid integration system

A solar PV plant grid integration system is designed in this paper, as shown in Figure 1. The system consists of two synchronous generators and one solar PV plant. In Figure 1, the rated active power of synchronous generator G1 is 500MW, and this value for G2 is 700MW. The rate power of solar PV plant is 300MW. The rate active power of Load1 is 300MW, and this value for Load2 is 1100MW.

GE model [5] is used for solar PV plant modeling in this paper, it is realized in DIgSILENT PowerFactory [6] using static generator as interface with the grid, the static generator is a controlled current source, as shown in Figure 2.

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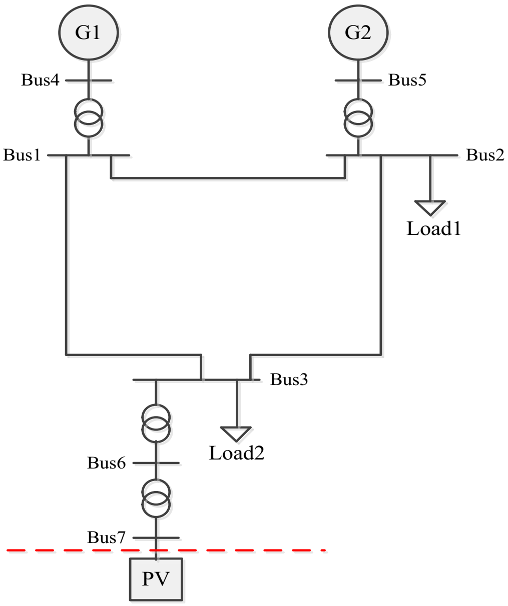


Figure 1. The PV plant grid integration system

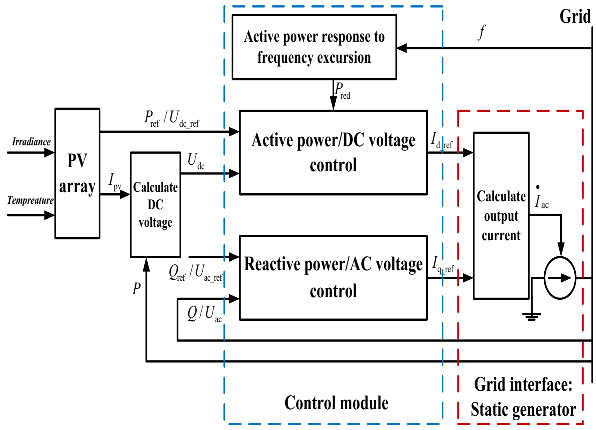


Figure 2. Model structure of PV plant

3 The hybrid data dynamic simulation method based on fast-responding generator and its realization in DIgSILENT PowerFactory

A large synchronous generator with a fast responding exciter and governor is used to inject the external signals. From the terminal of solar PV plant, the large synchronous generator can be seen as an equivalent of the rest of power system, as shown in Figure 3. The generator has very small impedance and transient time constants. A known set of signals (voltage, frequency, real power and reactive power) at Bus7 (see Figure 1 and Figure 3) can be obtained easily from regular measurements. Recorded bus voltage and frequency are input as reference values for the generator exciter (EXC) and governor (GOV) respectively [3]. Because of the large size of the generator and fast response controls, simulated bus voltage and frequency are forced to follow very closely the reference values, i.e. measured voltage V* and frequency f*.

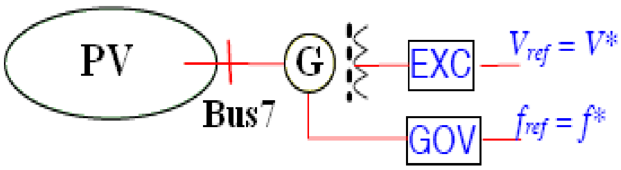


Figure 3. The PV plant grid integration system with a fast-responding generator

The measured values of bus voltage and frequency are all stored in text files, and they can be injected into DIgSILENT PowerFactory software, as shown in Figure 4. In PowerFactory the data can be fed into a generator exciter and governor model using Measurement File (ElmFile) format.
Type1 excitation system (EXC) model and type1 speed governor (GOV) provided by PSASP software [7] are used for synchronous generators in the simulation, the models all have been established in DIgSILENT PowerFactory, and validated by comparing with PSASP [8]. The models of EXC and GOV with injection data are shown in Figure 5.

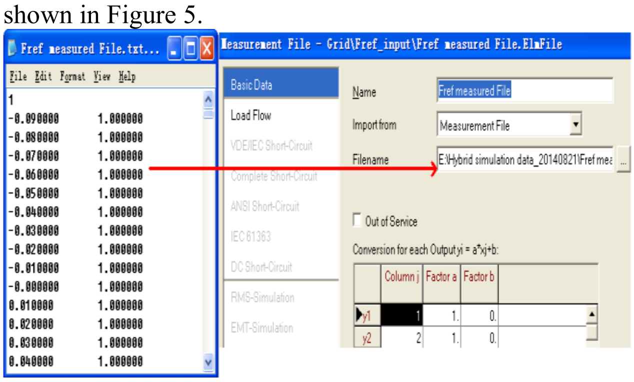
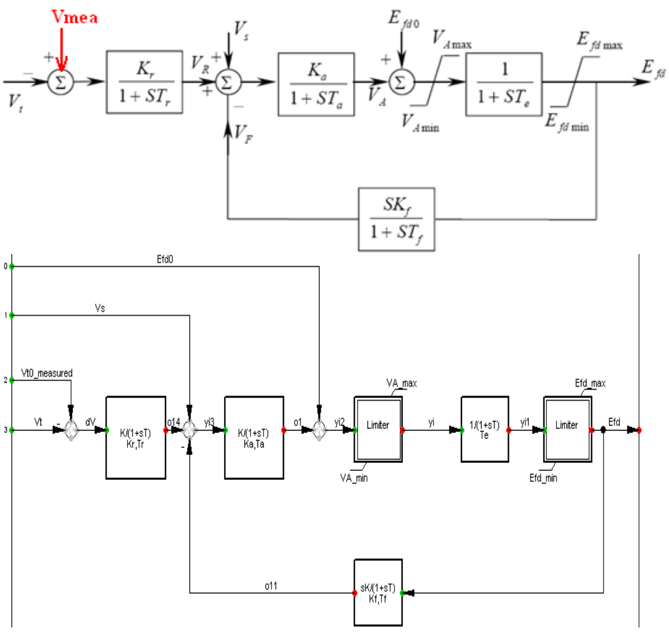


Figure 4. The application of measured frequency's text file in DIgSILENT PowerFactory



(a) Excitation system

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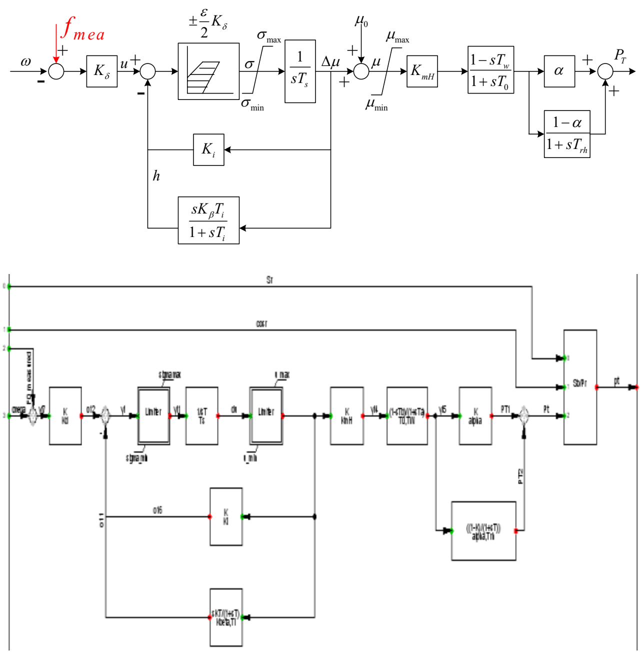


(b) Speed governor

Figure 5. The fast-responding generator's controller realized in DIgSILENT PowerFactory

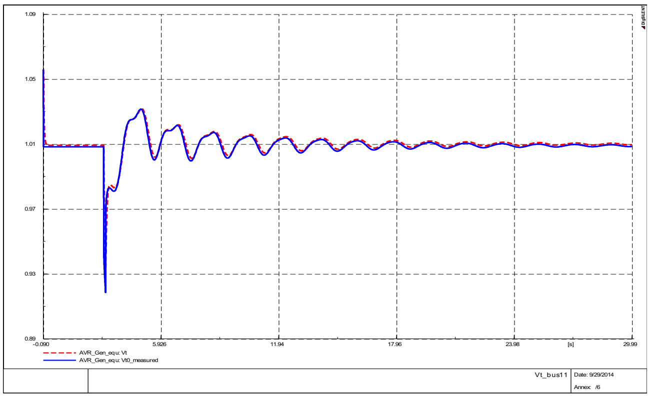
The parameters of EXC and GOV models used in simulation are listed in Table 1, the time constants are all very small to achieve a rapid control performance. For detailed explanations of the parameters, please refer to [7].

Table 1. The parameters of AVR and PSS models used in simulation.

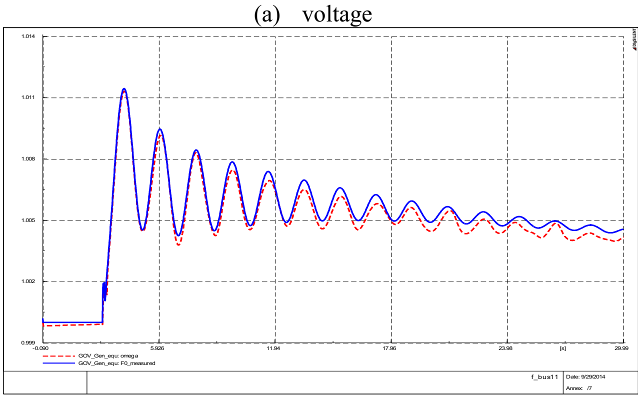
EXC		GOV		
Kr=1	Kf=0.04	Kd=20	T0=0.001	σ_{max} =1
Tr=0.001	Tf=0.001	K_{mH}=7	Tw=0	σ_{min} =-1
Ka=50	V_{Amax}=10	α =0.333	K_{β} =0	μ_{max} =1
Ta=0.001	V_{Amin}=-10	Ki=0.75	Ti=0.002	μ_{min} =0
Te=0.001	E_{fdmax}=5	Ts=0.001	Trh=0.002	
E_{fdmin}=-5				

4 Simulation results of solar PV plant model validation

Suppose that a three-phase symmetrical short-circuit happens on Bus3 (see Figure 1). This fault begins at 3s and is cleared at 3.1s. According to Figure 3, the measured values of Bus7's voltage and frequency are all stored and injected into PowerFactory as reference values. The comparison between simulation outputs and reference values under this scenario is described in Figure 6.



(a) voltage



(b) frequency

Figure 6. The comparison between simulation outputs and reference values

The difference between simulation outputs and reference values is acceptable. Then, we can compare the simulated real power and reactive power with the recorded values, if the difference is not small, it demonstrates that PV plant' simulation model or parameter is not accurate enough.

5 Conclusion

This paper presents a model validation methodology for solar PV plant via the hybrid data dynamic simulation based on fast-responding generator method. The implementation details of fast-responding generator method are disclosed for the first time. The simulation results illustrate the effectiveness of the proposed method in solar PV plant model validation.

Acknowledgments

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