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Feature distance based online cluster modeling of LVRT controlled PV power plants

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ABSTRACT

This paper presents a feature distance based online cluster modeling method for low voltage ride-through (LVRT) controlled photovoltaic (PV) power plant under partial shading. The proposed modeling approach uses the PV inverter feature distance weighted by parameter sensitivity as the clustering index and integrates an equivalent LVRT modelling strategy to describe the complete dynamic performance of the modelled PV power plant. The effectiveness of the proposed method is verified through the simulation results which also show that the method can accurately track the dynamic responses of PV power plant as the power distribution among different PV inverters changes.

1. Introduction

With the sharp increase of large-scale photovoltaic (PV) power plants, their dynamic behavior has much more impact on the stability of power systems [1–3]. Hence it is necessary to study the equivalent model of PV power plants for power system stability analysis and many efforts have been made to model the dynamic behaviors PV power plants [4–6]. However, there are still many challenges to build a perfect model that can reflect all actual characteristics of PV power plants, especially when they are suffering large disturbances. A large-scale PV power plant is usually consisted of huge numbers of grid-connected PV inverters delivering the generated PV power to the main grid. In addition to these inverters may be provided by different manufacturers, the models and the parameters of these inverters could be quite different. Consequently, the clustering modeling technique would be needed to obtain the accurate dynamic characteristics of PV power plants [7]. Meanwhile, the dynamic performance of PV power plants will also be affected under partial shading conditions in practice considering the cloud moving effect [8–10]. The output power distribution among inverters under partial shading conditions could be greatly different from that under uniform irradiance conditions in PV power plants [11–14]. As a result, online modeling technique should be employed to follow the momentary change of PV generation conditions in a better way. In addition to the above two factors, some researchers also investigated the impact of inverter low voltage ride-through (LVRT) control behavior on the dynamic characteristics of PV power plants [15–19]. These references validated that the LVRT control will significantly affect the dynamic performance of PV power plants. Therefore, an integrated equivalent model of a large-scale PV power plants necessitates considering these three factors at least.

In recent years, many researches are conducted to build equivalent models to study the dynamic behaviors of PV power plants [20–23]. Refs. [20] and [21] derived an equivalent aggregated model of PV power plants via aggregating all the PV inverters as a single inverter controlled by the synchronous power controller based on the Thevenin theorem. However, this model could not be applied for online analysis since it did not consider the situation that the control parameters of inverters may be different.

Ref. [24] presented an online clustering modeling strategy for PV power plants by taking the feature distance as the clustering index. Even under partial shading conditions, the clustering model is still of high accuracy. However, this method did not take the LVRT control into account, and thus it cannot match the actual characteristics of PV power plants. More recently, another online clustering modeling method of PV power plants has been proposed in Ref. [25]. This method used the distance of inverter unit impulse response

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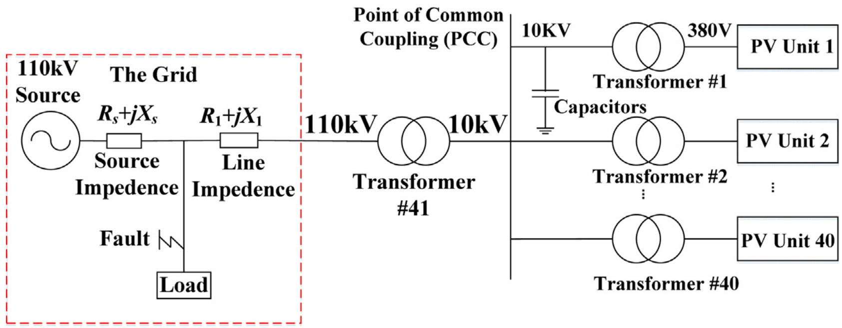


Fig. 1. System diagram of the investigated PV power plant.

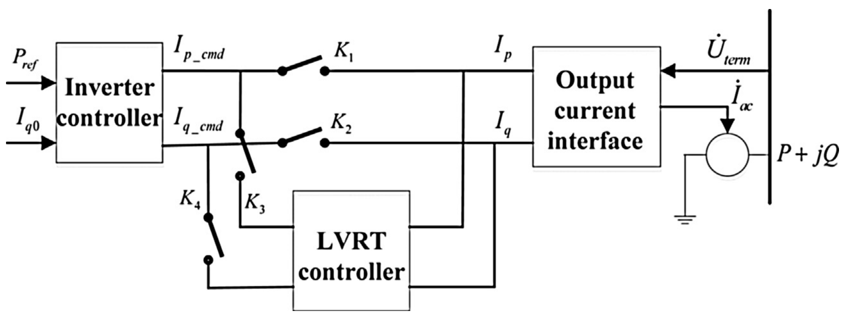
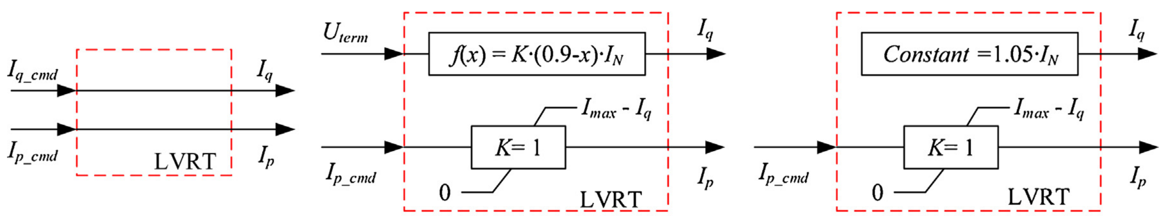


Fig. 2. Model of single PV generation unit.



(a) U_{term} > 0.9 (b) 0.2 ≤ U_{term} ≤ 0.9 (c) U_{term} < 0.2

Fig. 3. LVRT controller model.

(UIR) curves as the clustering index. However, the UIR method is not applicable for the situation with a larger degree of non-uniformity of irradiance.

Ref. [26] proposed a generic PV system model for transient studies based on the circuit topology and control scheme of a detailed three phase PV system. The model could be surly used in a single-PV system but did not address the description of the mixed dynamic behaviors of the PV units with distinctive characteristics in a large-scale PV power plant, especially when the output distribution of the PV power plant is time-varied. A simple clustering method was employed in Ref. [27] to model the dynamic effects of PV power plants, but the impact of more complex situations on the clustering results, such as partial shading and time-varied irradiation distribution, are not considered.

From the above literature review, it is evident that most of the PV system dynamic modeling studies only focus one or two aspects of the equivalent PV model. In order to fully describe the dynamic characteristics of PV power plants, this paper proposes an online clustering modeling method with taking the LVRT control function and partial shading situations into account. The proposed method uses the feature distance weighted by the online parameter sensitivity as the clustering index, and thus the clustering results can be automatically adjusted when the output power distribution among PV inverters changes. Therefore, even under partial shading conditions, the modeling method is still accurate. The proposed method also integrates an equivalent LVRT modeling strategy into the online clustering modeling method to consider the effect of inverter LVRT control.

The rest of the paper is organized as follows. Section 2 gives the PV system models which are used in the paper. Section 3 analyzes the limitations of the previous employed UIR method for online cluster modeling of LVRT controlled PV power plants. Section 4 presents the improved online modeling method. The case study results are investigated in Section 5. Section 6 discusses the application situation of the proposed modeling method. Conclusions are given in Section 7.

2. Investigated PV system

The system diagram of a PV power plant can be illustrated in Fig. 1, where 40 parallel PV generation units (each unit include inverter and PV panels) are connected to a 10 kV bus through step-up transformers #1–#40. Step-up transformer #41 connects all the PV units to the 110 kV transmission system. The capacity of each PV unit is 500 kW, thus the total capacity of the entire PV power plant is 20 MW. The main grid is represented as an ideal voltage source with its source impedance. $R_s + jX_s$ and $R_1 + jX_1$ are the source impedance