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Analysis of transient stability in distribution systems with distributed generation

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ABSTRACT

Transient stability in distribution systems has gained special interest due to the continuous increase of distributed generation connected to the grid. Besides the dynamic behavior of the generation system, distribution networks have extensive branches and unbalanced loads, with a specific set of equipment, increasing the complexity of the numerical analysis of transient stability. In this context, this work proposes a new methodology for transient analysis in distribution networks with distributed generation, divided in three major steps: the representation of the network model through a simplified model; the selection of disturbances types and buses for application, and the adjustment of stability control systems. The methodology is suitable for unbalanced networks and a demonstration of a single-pole switching is presented. Case studies are simulated and analyzed for a real network model.

1. Introduction

The analysis of transient stability is essential in transmission systems, and it has been addressed in many researches over the last decades. The impact of a large perturbation in a transmission line may lead to a widespread energy blackout and, therefore, efforts have been concentrated on modeling and analyzing the generation, protection and transmission systems subjected to this situation. Some of the well-established methods for these studies include Lyapunov stability, input-output stability, stability of linear systems, and partial stability [1,2].

Dynamic phasors and direct method of Lyapunov are the studied methods for application in power systems. For real systems, however, time domain simulation is widely used [3].

In the time domain, several works use the simplified network, reduced to the substation and the line that interconnect the generation [4,5]. It is representative only when studying the generation stability, however, for the distribution systems analysis, where besides the machines it is also desired to evaluate the reflection on the voltage and frequency imposed to the loads, this model is not satisfactory.

With the recent advances in renewable energy technologies, the increase of distribution generation (DG) directly connected to distribution networks is remarkable. In this case, distribution systems with a significant amount of DG may also be subjected to unstable operation in the event of a large perturbation in the grid [2].

Networks in the transmission systems are traditionally considered balanced, and an equivalent network between the substation and the DG is sufficient for a transient stability analysis.

The peculiarity of distribution systems is an important feature in this scenario, which operates in a predominance of unbalanced loads [6] and limited control devices. For Volt-Var control, some important devices include capacitors banks and automatic voltage regulators (AVR), and for network protection, reclosers and fuses are worthy to be mentioned.

These conditions, combined with abrupt and unpredictable variations of DG, bring a concern on their dynamic behavior and, consequently, the impact on power quality due to the diversity of sources [7].

In transmission systems, the small signal of stability and transient stability are essential studies, that show, through analytical methods or simulations in the time domain, the dynamics of the generators and the responses of the controls over events in the system [6–10]. However, this type of analysis is not suitable for direct use in distribution systems, since the characteristics are not the same [6,11].

There are few researches that explore transient stability studies in distribution systems, and most of them focus on the response of synchronous machines subject to load unbalance [12–14] with a generator-load model, without inclusion of the distribution networks. Recent studies consider the analysis applied only in hypothetical networks, and do not contemplate events in branches, which are significant for this kind of analysis [3,6].

The main contribution of this work is the proposal of a methodology

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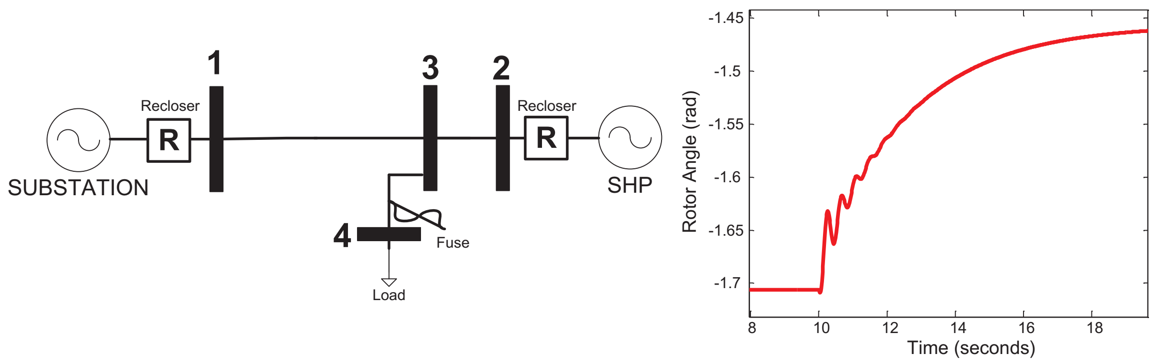

(a) Distribution network (b) SHP generator rotor angle

Fig. 1. Simulation of a branch fault in a distribution network.

Table 1
Operational limits.

Variable	Acceptable values	Description
δ_i	$<\delta_{critical}$	Rotor angle of the machine in continuous operation
ΔP	$\leqslant$ 0.5 p.u.	Torsional stress
TV	0.80 p.u. $\leq$ TV $\leq$ 1.10 p.u.(normalize to TV in 10 s)	Level voltage in transient state
SV	0.95 p.u. $\leq$ SV $\leq$ 1.05 p.u.	Level voltage in steady state
TF	56.5 Hz $\leq$ TF $\leq$ 66.0 Hz(normalize to SF in maximum 30 s)	Frequency in transient state
SF	59.9 Hz $\leq$ SF $\leq$ 60.1Hz	Frequency in steady state

Where: P: Active power; TV: Transient Voltage; SV: Steady state Voltage; TF: Transient frequency; SF: Steady state frequency.

for global stability analysis in distribution systems, which highlights:

(a) Network simplification technique for transient stability studies, by creating a representative model for dynamic analysis;
(b) A selection criteria establishment of main branches with potential impact in the angular stability, by considering the protection devices characteristic of distribution systems;
(c) Dynamic models representation with specific parameters for DG in distribution networks;
(d) Evaluation of single-pole disturbances in distribution systems;
(e) Control system adjustment in conditions of instability.

In order to demonstrate the application and effectiveness of the methodology, case studies of a real network model are presented and discussed.

2. Problem formulation

For a specific initial operating condition, an electric power system can be classified as stable if it is able to “regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact” [15].

The primary concern in the stability analysis is to verify the synchronism of the generator machines in a short period of time after the occurrence of a disturbance, during which the actions of the controllers do not have a significant effect [9].

The increase in the DG penetration in a distribution system does not significantly affect the speed of the machines regarding the synchronous speed, but it causes an increase on the oscillation frequency after a fault [15]. Synchronous generators connected to distribution systems present small rated power and have low inertia, what results in a system with a higher probability of losing synchronism and hence stability

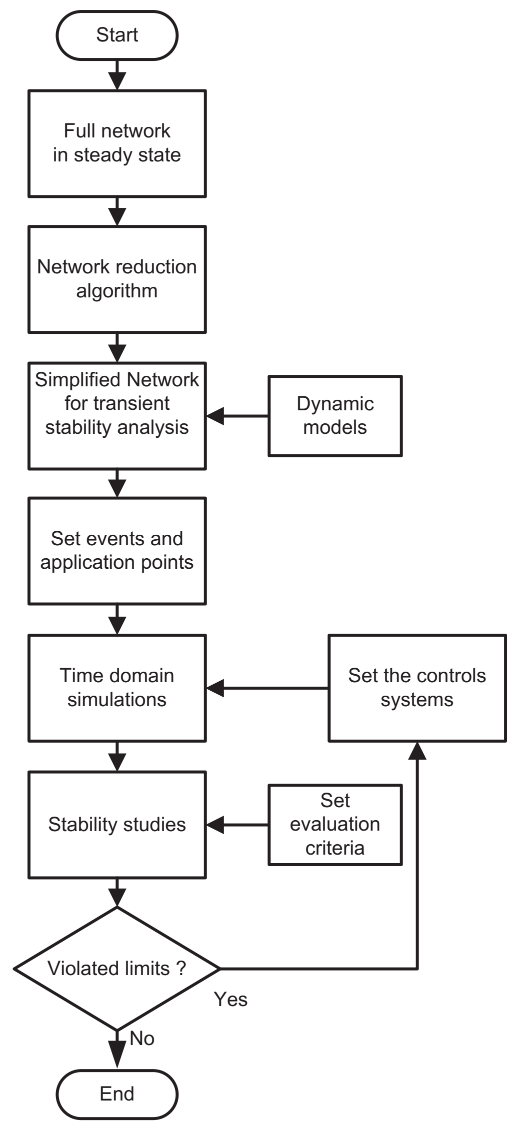

Fig. 2. Methodology flowchart.

[10,16]. For this reason, especial attention to protection systems should be given, avoiding overvoltage, overcurrent and unintentional islanding.

In distribution networks, load unbalance and branches with large extension shall be considered in transient simulations, as they may cause interference in the responses of the generator machines and in the