Electric Power Systems Research 122 (2015) 104–118

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Overview of electrical protection requirements for integration of a smart DC node with bidirectional electric vehicle charging stations into existing AC and DC railway grids

F. Sanchez-Sutil[a], J.C. Hernández[a,*], C. Tobajas[b]

[a] Dept of Electrical Engineering, Jaén University, Campus Lagunillas s/n, Edificio A3, Jaén 23071, Spain
[b] ADIF (Spanish Railway Infrastructure Manager), Strategy Management and Development, C/Titan 8, Madrid 28045, Spain

ARTICLE INFO

Article history:
Received 21 March 2014
Received in revised form
30 December 2014
Accepted 2 January 2015

Keywords:
Protection
Electric vehicles
Railways
Distribution networks
Photovoltaic power systems
Power system protection

ABSTRACT

Distribution network operators (DNOs) and railway traction system operators (RTSOs) who will connect bidirectional electric vehicle charging stations (EVCSs) (treated as both load and source) to their power networks need a unified set of requirements for safe operation. However, such requirements are currently unavailable. Accordingly, the authors in cooperation with the Spanish national RTSO and the most important Spanish DNO have elaborated a unified regulatory framework of requirements for the interconnection protection systems and the earthing arrangement of a DC node used as a reference to feed bidirectional EVCSs, now under construction. This node connects a 0.4-kV AC secondary distribution network (SDN), a 25-kV AC railway traction system (RTS), a 3-kV DC RTS, a local distributed resource (DR) system, and two bidirectional EVCSs. The DR system includes both a photovoltaic PV system as well as backup storage systems (battery and supercapacitor). Thus, the DC node has all the potential interconnections to serve as a reference for requirements regarding the interconnection of bidirectional EVCSs.

This unified regulatory framework is the result of a critical review which enabled us to modify, harmonise, and adapt requirements in a wide range of grid-interconnection standards and codes as well as company operation practices to the specific behaviour of bidirectional EVCSs. This is particularly important for RTSs where the interconnection of this reference DC node significantly changes the protection practices of RTSOs and the RTS earthing arrangement. This unified framework is proposed as a technical specification for the companies involved in the implementation of this type of DC node to feed bidirectional EVCSs.

Contents

* Corresponding author. Tel.: +34 953212463; fax: +34 953212478.
E-mail address: jcasa@ujaen.es (J.C. Hernández).

http://dx.doi.org/10.1016/j.epsr.2015.01.003
0378-7796/

1. Introduction

Electric vehicles (EVs) reduce the CO_2 emissions generated by the transportation sector [1–3]. However, their large-scale use involves the massive implantation of EVCSs in traditional distribution networks with numerous associated grid impacts [4–6]. Furthermore, it is expected that this implantation will include RTSs [7–10].

The first challenge arises from the fact that transportation movements end at approximately the same time as the peak electricity demand. There should thus be a demand side management focused on encouraging users to recharge EVs at off-peak times, when the power demand is lower [4,6,11–13].

Although EVs now only store power from the grid (grid to vehicle, G2V), the second challenge will surface when EV batteries must also deliver power to the grid (vehicle to grid, V2G) to provide ancillary services to the power system [14–16]. Furthermore, EVCS should be treated as both load and source, with bidirectional power flow capacity (i.e. DR). Therefore, the limited hardware requirements and simplified interconnection issues for unidirectional EVCSs do not apply.

The third challenge is related to the heterogeneous sources that generate power for EVCSs. The reduction in CO_2 emissions should be based on the inclusion of renewable power in these stations [1–3] (e.g. PV power or 'renewable' power, such as regenerative braking power in RTSs [7,17]). Despite the fact that such power is relatively easy to obtain, its integration into the network is problematic because of its intermittent behaviour and also because production is difficult to predict.

In this context, the definition of a DC node used as a reference to feed bidirectional EVCSs in the SDN and RTS context requires a combination of new technologies, the optimal exploitation of existing infrastructure, as well as changes in the operation and protection practices of power companies. To make this a reality, the *FerroSmartGrid* project [18] is now developing new products and services for this type of DC node. The reference DC node defined connects the following elements: (i) a 0.4-kV AC SDN; (ii) a 25-kV AC RTS; (iii) a 3-kV DC RTS; (iv) a local DR system including PV power and backup storage systems (i.e. battery and supercapacitor); and (v) two bidirectional EVCSs.

FerroSmartGrid lays the foundations for the safe, efficient, and smart interconnection of complementary AC and DC sources which feed bidirectional EVCSs, thanks to a reference DC node. The research presented in this paper is a part of this project which focuses on the elaboration of a unified set of requirements for interconnection protection systems and the earthing arrangement of this reference DC node. This will guarantee its safe use.

Section 2 of this paper discusses the aim of the study. Section 3 presents the configuration of the reference DC node, where the research was performed, and Section 4 describes the functions of an interconnection system. Section 5 presents the electrical protection requirements, specifically adapted and harmonised to the reference DC node, Sections 6–9 discuss the requirements for each interconnection protection system and earthing arrangement of the reference DC node, namely, 25-kV AC RTS, 3-kV DC RTS, 0.4-kV AC SDN, bidirectional EVCSs, a backup storage system, and PV system. This proposal targets protection relays, their settings, and earthing requirements. For interconnections to RTSs, the relevant network protection is first described since careful coordination is required. Finally Section 10 lists the conclusions that can be derived from this research.

2. Aim of the study

The interconnection of bidirectional EVCSs (i.e. DRs) to SDNs and AC/DC RTSs can only be implemented when safe network operation is guaranteed by suitable electrical protection requirements. These requirements constitute the electrical interconnection protection that allows the SDNs and AC/DC RTSs to operate safely and is often viewed as the single most important technical requirement [19]. It is vital to distinguish interconnection protection from network protection and EVCS protection.

Currently, the interconnection of bidirectional EVCSs must be approved by the DNO or RTSO as the case arises. Because of the recent proliferation of EVCSs, the DNO or RTSO now has greater responsibility, and would doubtlessly benefit from a unified set of requirements for the interconnection protection system and the earthing arrangement if they were available. In addition, when an intermediate DC power bus is required, its security should also be guaranteed.

An EVCS is connected to SDNs or AC/DC RTSs by means of an AC/DC or DC/DC converter. Nevertheless, when more than one source feeds the EVCS, as in the case of the interconnection of different DRs [20], an intermediate DC power bus is advisable for the interconnection. Many references focus on the monitoring, operation, and power sharing in a DC power bus [20–24].

The connections of EVCSs usually have unidirectional power flow capability, but the new V2G approach [14–16] requires that this capability be extended to a bidirectional power flow. Bidirectional capability is the usual condition for the connection of several sources in an intermediate DC bus [20].

Despite their importance, there are currently no electrical protection requirements for the grid-interconnection of bidirectional EVCSs (i.e. DRs). Thus, in regards to SDNs, recent regulations [25,26] only include requirements to protect EVCSs from internal faults and abnormal internal operating conditions. This is the EVCS protection. The reason for this is that EVCSs have always been regarded as passive loads. This approach is also followed in the only European standard available (series IEC 61851 [27]), which is the only one that deals with EVCS protection, among other issues. Therefore, these requirements [25–27] are insufficient for the grid-interconnection