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Virtual power plant architecture using OpenADR 2.0b for dynamic charging of automated guided vehicles

Mitja Kolenc[a], Norman Ihle[b], Christoph Gutschi[c], Peter Nemček[c], Thomas Breitkreuz[d], Karlheinz Gödderz[e], Nermin Suljanović[f,g], Matej Zajc[h,*]

[a] ELES, d.o.o, Hajdrihova 2, 1000 Ljubljana, Slovenia
[b] OFFIS e.V., 26121 Oldenburg, Germany
[c] cyberGRID GmbH, 1190 Wien, Austria
[d] Vattenfall Europe Energy Trading GmbH, 20354 Hamburg, Germany
[e] Vattenfall Europe Energy Information Services GmbH, 22297 Hamburg, Germany
[f] Faculty of Electrical Engineering, University of Tuzla, 7500 Tuzla, Bosnia and Herzegovina
[g] Milan Vidmar Electric Power Research Institute, 1000 Ljubljana, Slovenia
[h] Faculty of Electrical Engineering, University of Ljubljana, 1000 Ljubljana, Slovenia

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ABSTRACT

This paper investigates a virtual power plant (VPP) using the OpenADR 2.0b communication protocol to securely and reliably operate distributed energy resources (DERs) over public Internet infrastructure, providing ancillary services to the transmission system operator (TSO). VPP performance analysis was based on an experimental setup as well as a dynamic behavioural model and numerical simulations. The experimental setup consisted of battery stacks from automated guided vehicles at a harbour container terminal. Within this experimental study, we analysed data exchange utilising the OpenADR protocol over a four-week period between the VPP in Slovenia and the terminal management system in Germany by assessing the selected quality of service parameters – latency (round-trip time), packet loss, retransmissions, bandwidth, amount of traffic and message patterns. The impact of latency on performance of the VPP aggregating battery stacks with other DER types was investigated using numerical simulations. Load profiles for the selected DERs and communication channel models were derived from field measurements.

1. Introduction

Currently power systems are facing challenges at transmission and distribution levels, including high peak consumption, constantly increasing complexity, and a growing share of distributed energy resources (DERs) [1,2]. Besides balancing with conventional peaking power plants, DERs can be utilised as a flexible capacity for providing ancillary services [3–5].

New flexibility approaches based on demand response, energy storage and distributed generation [3–8] utilise virtual power plants (VPPs) to aggregate and control small- and medium-scale DERs (hydro, wind and photovoltaic power plants representing renewable energy resources; other distributed generation (DG) units; and battery energy storage systems, electric vehicles, etc.). The DERs' scheduling problem is discussed in a comprehensive review on microgrid and VPP concepts in [9]. The optimal management of renewables within the VPP concept is addressed in [10], and the optimization algorithms for managing electrical energy in unbalanced distribution networks using the VPP concept are presented in [11]. The economic assessment and modelling of VPPs are investigated in [12,13] with a focus on reducing their operational costs and maximizing profit by using appropriate bidding and market strategies.

VPPs are becoming an integral part of smart grids by combining several small DERs – in particular, commercial and industrial consumers – to provide ancillary services, including scheduling and redispatch, reactive power and voltage control, congestion management, load-frequency control and imbalance management. Focusing on load-frequency control, VPPs can be engaged in manual frequency restoration reserve (mFRR) and automatic frequency restoration reserve (aFRR) processes [3,14,15]. Recent research has focused on different aspects of VPP utilisation for providing ancillary services: economic viability [13,16], optimal control and dispatch strategies [17,18] and scheduling [19,20]. In this paper, we focus on the efficient and reliable use of VPPs for providing ancillary services from a communication

* Corresponding author.
E-mail address: matej.zajc@fe.uni-lj.si (M. Zajc).

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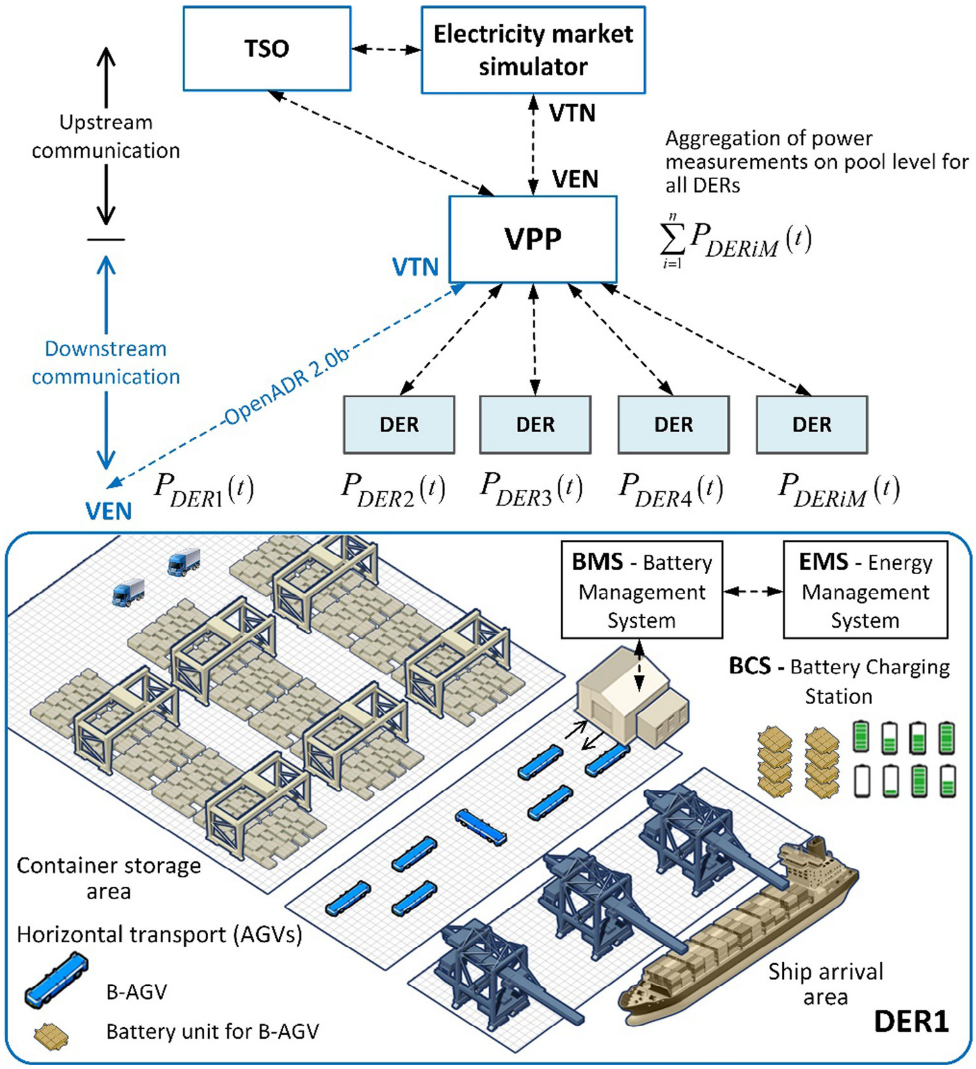

Fig. 1. The experimental setup.

system perspective.

By integrating DERs into pools with relevant sizes (also known as pooling), VPPs can offer flexibility services to the transmission system operator (TSO) as a cost-efficient and reliable alternative to conventional peaking power plants [21]. Flexible capacity also offers the potential to utilise resources for generation or consumption according to external signals (e.g., price peaks in intraday power trading) which need to be efficiently and reliably exchanged between the VPP and DERs using communication infrastructure and protocols [22].

1.1. VPP communication infrastructure and protocols

VPPs are typically geographically distributed systems requiring advanced information and communication technologies (ICT) for tasks such as monitoring and control, data transmission and data management [3]. Different ancillary services require specific levels of communication system performance for undisturbed and reliable operation [23]. Reliable and secure communications are crucial for bidirectional, near-real-time information exchange both downstream towards different DERs and upstream towards the TSO and electricity market [24,25] (Fig. 1).

Timely delivery of setpoint and measurement signals, exchanged between the TSO, the VPP and the DERs, is crucial. In the case of conventional power plants, reliable proprietary communication links (e.g., optical or radio) with a high bandwidth are typically utilised. This is usually not the case with smaller, geographically distributed DERs [24,25], in which cloud-based VPP deployments are more appropriate [25].

Communication systems are one of the key factors impacting the technical and economic feasibility of VPPs [26]. Public Internet connectivity is a pervasive and cost-effective solution for connecting VPPs and DERs. Before actual VPP deployment, we must determine whether utilising Internet access provides sufficient quality of service (QoS) to ensure reliable and secure VPP operation. Communication protocols must also provide efficient communication between different nodes as well as mechanisms for timely message exchange.

Several communication technologies (wired or wireless) already in use in the power domain can be utilised for VPPs as long as they conform to operational requirements [24]. The selection of an appropriate communication technology depends on application requirements, availability, economic viability and the requested level of reliability [25]. In this research, we investigated a combination of wired technologies (fibre and twisted pair) at the physical layer, comprising the public Internet infrastructure. Use of cellular communication technology (e.g., 3G or 4G) could also be considered; however, such analysis is beyond the scope of this paper [27].

Utility remote control protocols – for example, IEC 60870-5-104, DNP3 and Modbus – are well accepted in the power system automation domain [16]. These protocols provide a sufficient solution for technical VPPs (TVPPs) aggregating DERs from the same geographical area for

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