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Towards improving throughput and reducing latency: A simplified protocol conversion mechanism in distributed energy resources network

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HIGHLIGHTS

- This solution facilitates interoperability between Modbus and IEC 61850.
- This solution reduces delay around 40%, compared to the existing solution.
- This solution increases throughput around 40%, compared to the existing solution.
- This solution reduces delay variance by 0.35 ms, compared to the existing solution.
- Proposed solution is expected to be cost effective and more reliable.

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ABSTRACT

With our research on communicating entities in heterogeneous Distributed Energy Resources (DERs), which utilize both IEC 61850 and other legacy interfaces, we show two things: firstly, (1) how the commonly deployed methods of achieving interoperability between incompatible interfaces can be altered to optimize throughput and latency; secondly, (2) how large an effect the optimization has by quantifying delay and throughput for the common method and our new method introduced in this paper.

A prime objective of DERs is to enhance efficiency, stability and safety management during an emergency. Timely availability of operational data on DER entities in remote management centers will allow management software to extend the capabilities of, for example, an emergency generator to predict and correct for failure or operate more efficiently in a DER with mix of energy production types (solar, wind, petrol and so on). A DER often integrate a variety of entities which have proprietary incompatible interfaces (e.g. Modbus, DNP3, RS-485 and IEC 60870). To facilitate interoperability a protocol conversion mechanism is necessary. Here we concentrate on communication between the relatively modern IEC 61850, and Modbus, the most common proprietary interface.

For our research, we built a new entity which integrates two other entities which are normally separate devices in a DER: a DER Management Server (DER-MS) and Modbus Feeder Master (MFM). Consolidating these two entities into a single box allows us to replace network inter-process communication with local inter-process communication, eliminating significant time sending messages from the remote management centers to peripheral elements in a DER (e.g. emergency generators) and back again. Using the same DER, we quantified network delay and throughput for: (a) our newly built simplified protocol conversion device and (b) the common configuration with MFM and DER-MS. We tested both configurations by benchmarking data requests from a remote management center to an emergency generator. Latency and throughput results obtained through experiment demonstrate that, our solution outperforms the common configuration with MFM and DER-MS.

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1. Introduction

To overcome the limitations of power shortages and improve reliability of power supplies, the usage of Distributed Energy Resources (DERs) (e.g. Emergency Diesel Generator (EG), photovoltaic cell, wind turbine and energy storage system) is becoming popular [1,2]. Some Governments (e.g. S. Korea) are starting to mandate installation of DERs in buildings to reduce energy demand during peak hours and provide uninterrupted power supplies. It is reported in [3] that, to date, a total of 70,606 EGs are installed in buildings in S. Korea (that accounts for roughly 21% of the capacity of national grid). With new buildings and ever-expanding energy demand, it is expected that the number of DERs will increase sharply. In order to properly use and ensure reliable energy supplies from different DERs, it is increasingly important to establish robust management and operational systems.

To ensure uninterrupted power supply and reduce energy generation cost, the concept of Virtual Power Plant (VPP) is gaining importance [4,5]. A VPP integrates several types of DERs, which may or may not be physically located in the same place. The management and orchestration function of VPPs and their DERs is provided by a Remote Management Center (RMC). RMCs are vital in ensuring availability and safe operation of DERs [6,7]. Reliable and effective inter-networking is vital for their operation.

A VPP will have several DER components which may have heterogeneous communication interfaces. Different vendors use their own proprietary interfaces in their DER equipment [8,9]. There are at least 60 legacy interfaces such as Modbus, DNP3, RS-485, and IEC 60870. In order for legacy DER equipment to communicate with the modern standardized equipment (equipment with IEC 61850 based interfaces) a translation function is required. This is normally provided by a standalone entities, such as, a black-box device installed next to the communicating equipment.

To ensure smooth operation of DERs and an uninterrupted power supply, an RMC needs to periodically retrieve information from its connected DERs. In the case of an emergency generator, important indicators of the health can be obtained by collecting time series information (e.g. voltage level, fuel level and coolant temperature) which can then be used by the RMC to improve the EGs' safety and performance.

In Fig. 1 we present two graphs, (*left*) fuel level over time and (*right*) coolant and oil temperature over time. The data plotted was obtained from our testbed DER EG and shows the information to manage smooth operation of power generation. Under normal operation, coolant and oil temperature show a strong positive correlation. Clearly, if this relationship changes significantly, that is cause for concern and the RMC should take measure to shut down the EG safely. Similarly, if the fuel level changes while the EG is currently switched off, the RMC should flag this EG for maintenance and perhaps take the DER off-line from power production. One can easily imagine temperate information being used to detect abnormal operation and flag safety issues. Suppose the coolant and oil temperature is over 90 °C at a given time, upon receiving this information, the RMC needs to decide on whether the current temperature falls within the acceptable limits or not. If it does not, the RMC needs to immediately trigger the EG to be shut down.

In order to take advantage of performance information (discussed above) its timely collection is of paramount importance [10–12]. For example, the window of opportunity to take advantage of oil temperature or oil pressure readings in a catastrophically failing EG is short. The prime objective of our research is to improve throughput and reduce latency in VPPs with heterogeneous DER interfaces including IEC 61850.

We designed and implemented a novel IEC 61850 server that facilitates protocol conversion between Modbus and IEC 61850. Modbus is an important and widely adopted legacy interface (it has been reported in [13–15] that around in 7 million nodes have been deployed across North America and Europe with the Modbus interface). Normally, to ensure compatibility between Modbus and IEC 61850 interface two protocol conversion entities–Modbus Feeder Master (MFM) and DER Management Server (DER-MS)–are required (e.g. [16–20]), see Fig. 2. This is used to facilitate protocol conversion but has several limitations, including high latency, low throughput and greater implementation complexity. Our solution is designed to reduce latency and improve throughput by consolidating those two conversion entities into one and replacing network Inter-Process Communication (IPC) between the MFM and DER-MS with local IPC within a single host. In this paper, we will refer to this consolidated entity as Advanced-DER-MS, this concept was briefly described in our earlier work [21,22].

With the consolidation of the two network entities, the message exchange changes from network communication between entities to communication between processes on a host. While the logical flow of communication is very similar, we use IPC based on shared memory instead of TCP/IP based IPC. This local IPC scheme together with the consolidation into the Advanced-DER-MS, we will term as Simplified Protocol Conversion Mechanism (SPCM). We will refer to the normal dual entity based solutions (e.g. [18–20]) as Conventional Protocol Conversion Mechanism (CPCM).

To quantify our research, for this paper, we implemented and compared the performance of SPCM and CPCM in a VPP testbed (located in the Jeonbuk provincial office, S. Korea). The results obtained demonstrate that SPCM dramatically improves data retrieval performance in heterogeneous DERs compared to CPCM.

The remainder of this article is organized as follows. Section 2 discusses relevant research. Section 3 presents details of our novel SPCM. A performance comparison between SPCM and CPCM is presented in Section 4. Section 5 discusses ideas for future research. Finally, Section 6 concludes this paper.

2. Related work

Smart grid information modeling and protocol conversion among

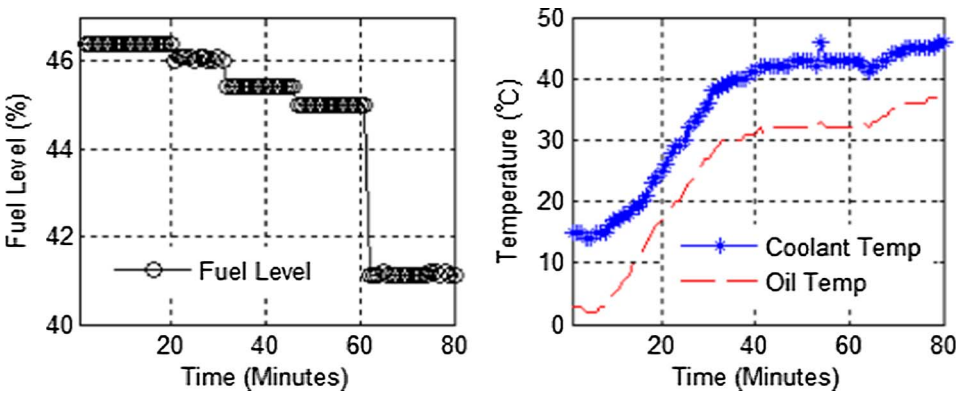

Fig. 1. Collected time series data of an EG in our testbed: Fuel level (*left*) and Coolant and Oil temperature (*right*).