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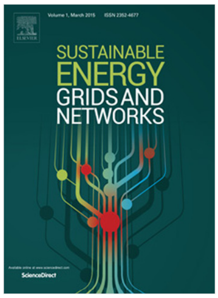

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Rasmus Pedersen, Mislav Findrik, Christoffer Sloth, Hans-Peter Schwefel

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Network Condition Based Adaptive Control and its Application to Power Balancing in Electrical Grids

Rasmus Pedersen, Mislav Findrik, Christoffer Sloth, and Hans-Peter Schwefel

***Abstract*—To maintain a reliable and stable power grid there must be balance between consumption and production. To achieve power balance in a system with high penetration of distributed renewable resources and flexible assets, these individual system can be coordinated through a control unit to become part of the power balancing effort. Such control strategies require communication networks for exchange of control loop information. In this work, we show how a congested communication network can have a dramatic impact on the control performance of such a power balancing controller. To alleviate potential stability issues and increase control performance, an adaptive control design is proposed together with a communication network state estimation algorithm. Extensive simulation studies on a realistic model of a low voltage residential grid, using network traces obtained from a real powerline network, show significant performance improvement when the adaptive controller is used.**

***Index Terms*—Power Balancing, Networked Control Systems, Communication Network Estimation, Power Distribution Grid Control.**

I. INTRODUCTION

The growing need for sustainable energy supply is resulting in increased installation of renewable energy generation resources in todays' electrical distribution grids [1]. Such power generating resources are distributed across medium voltage (MV) and low voltage (LV) grids, and are characterized by having a highly volatile power production given by environmental conditions such as wind speed and solar irradiation. This ongoing transition is challenging the system operators [2], and they are demanding new control features enabling them to maintain a reliable electrical grid with a high quality of power delivery [3].

Grouping local loads with renewable production units allows operators to construct microgrids (MGs) and maintain power balance, by coordinating these units along with flexible assets, such as energy storages. The MG is one of the key concepts that can strengthen grid resilience and mitigate large power blackouts [4]. Each MG must be able to operate autonomously in islanded mode and be capable of coordinating generating resources to meet consumption demand [5]. However, operating a MG over communication networks brings challenges for control algorithms, which require low latency and reliable network performance. In this paper, a hierarchical approach for managing flexible units in a MG is presented, where a particular focus is placed on the design of an adaptive controller that is stable despite congested and non-ideal communication links.

Successful control over imperfect networks could significantly lower infrastructural costs by enabling usage of existing communication networks. Nowadays, xDSL, fiber optics, DOCSIS, and cellular networks (e.g. GPRS, UMTS, LTE) are already widely deployed by the telecom operators in Europe with high coverage [6], hence they could be used for connecting the flexible units with the MG controllers. Alternatively, grid operators may want to deploy their own infrastructure, desirably using off-the-shelf technologies such as wireless mesh networks (e.g. 802.15.4 or 802.11) or powerline (PLC) communication, which do not require additional cabling [7]. When these networks are shared between several Smart Grid applications (e.g. advanced metering or demand response programs) or other units generating traffic, they may not deliver the network performance required by the control algorithm. In Fig. 1, it is illustrated how congesting the communication links of the powerline communication is impacting a power balancing controller tuned for a non-congested communication network. During periods with no congestion the network delays are negligible and the controller follows the given reference tightly, however during the periods with congestion the communication links experience high delays, resulting in oscillatory closed-loop behavior.

The control of power systems over communication networks has been addressed in several papers. In [8] they analyse the need for new real-time control features and the need for gathering information from distributed resources through communication channels experiencing delays and loss of information. They illustrate the consequences of large delays on the operation of power systems and briefly mention possible solutions. However, the work does not cover time-varying communication network state or the coordination of distributed systems on a low voltage level, where computation power is limited and communication networks are shared with several other systems. The approach taken in [9] is based on linear matrix inequalities to compute a controller which is stable under some given delay interval. The robust control law easily becomes conservative, as they do not consider adapting the system to different magnitudes of delays. Instead, they provide a guarantee of stability for the largest delay value.

In this work, a procedure for designing a controller capable of adapting based on communication network properties is presented. To coordinate the flexibility of assets the method relies on consensus algorithms, which are suitable for large

Rasmus Pedersen and Christoffer Sloth are with the Department of Electronic Systems, Automation and Control, Aalborg University, Denmark; e-mail: {rpe,ces}@es.aau.dk.
Mislav Findrik is with Austrian Institute of Technology (AIT), Digital Safety and Security Department, Vienna, Austria; email: mislav.findrik@ait.ac.at.
Hans-Peter Schwefel is with GridData (www.griddata.eu) and the Department of Electronic Systems, Wireless Communication Networks, Aalborg University, Denmark; email: hps@es.aau.dk