Invited Session "Control in Smart Cities" Summary Statement

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Abstract— **Smart Cities and supporting technologies are a rapidly emerging research trend that incorporates interdisciplinary approach of several distinctive areas: energy and grid management, transport, infrastructure, and above all, integration methods based on information and communication technologies (ICT). Finally, the concept aims at complete energy independency of the city and its subsystems as one of the main characteristics, which is expected to elevate new control theories and applications, but also to leave its mark on advancing the society.**

Buildings are identified as the world's largest energy consumers and are undoubtedly entering an era of comprehensive changes and multidisciplinary trends where ICT is suitable as an integration tool for different technologies for increasing the energy efficiency, i.e., achieving the zero-energy level. Multidsiciplinarity results in an increased need for high-end technology and highly competent experts with long-lasting procedures for modelling and consumption forecasting, which, from the economic perspective, is identified as the main obstacle to implementation of new technologies. Decentralised control trends are inherently overcoming the problem while keeping the subunits of the system independent in technology, legal and privacy aspects.

By integration with renewable energy sources, buildings are becoming capable for active participation in distributed energy market. Buildings are integrated mutually, with electrical vehicles and infrastructure, into smart districts, grids, and finally cities. Papers in this special session will contribute to control area with focus on buildings and transport energy efficiency increase, and coordination of the two for energy- and cost-optimal behaviour.

Keywords: Energy efficient systems, Predictive control, Renewable energy and Sustainability

I. Summary Statement

A. Outline and motivation

With 40% of total primary energy spent for buildings operation, numerous policies and initiatives directed towards their energy efficiency increase have emerged. The EU 2030 Energy Strategy, built on promising results and well-adopted research and implementation trends of the previous 20-20-20 strategy (CO2 reduction – renewables share – energy savings), targets towards 40-27-27 by the end of year 2030 [1]. A significant focus is put on the buildings sector as the largest energy consumer. Ongoing research on smart grids, system of systems and internet of things created an opportunity to push savings further with systematic improvements of electrical, heating or water supply systems. Integration of these thoroughly diverse complex systems is enabled by high-level management methods where model predictive control (MPC) has emerged as a promising optimal and flexible technique [2].

Application of the MPC to building energy management had a great impact on research trends and contributed with experimentally validated building energy efficiency increase by 17% [3] to 28% [4] (theoretically expected up to 70% [5] in particular comprehensive applications), heat pump energy savings of 13% [6], load shifting possibility [7] for power grid balancing or additional economic savings with hourly-variable electricity prices [8]. Furthermore, introduction of microgrid with distributed power generation and storage units allows buildings to enter the energy market as active participants and ensure revenues [9] with bidding strategies, where increase in profit is achieved with combined microgrid and building climate control (e.g. by about 15% in [10]). With inherent ability to handle constraints, MPC has lead to the system reliability and improvement of users comfort at the same time when compared with state-of-the-art adopted control methods. This is also expected to contribute to productivity within commercial buildings.

Buildings today are complex systems composed of many subunits responsible for maintaining safe and steady operation such as: sensors, thermal actuators, zone (room/office) climate controllers, central heating/cooling medium production units, medium supply ducts, lighting, shading, fire alarms and security systems. Recently, photovoltaic systems, wind turbines, energy storage units with corresponding charging curves are also included in the form of a microgrid. These subsystems are all very different in dynamics, priorities, means of operation but also implementation aspects such as energy levels, protocols, maintenance services, etc. Rather than having one large control structure to handle all the subsystems at once, it is more natural to separate it into subunits in a hierarchical or distributed way [14–16]. In addition, many of the listed subsystems can be subjected to optimization methods, and many researches are focused on addressing a particular case of chosen building subsystem. Examples of recent contributors in general control theory and distributed control topics are in topological approach of robust hierarchical control [14] or solvers efficiency increase with decentralized active-set method [17] for systems with communication delays or in distributed alternating direction method of multipliers [18]. The overall lack of contribution in the research domain so far is observed in an integration method of thoroughly distinct technologies, especially with included practical knowledge and user-experience with smart city technologies. Initial trends are observed in treating buildings as heat storages [7, 11] through HVAC systems and the area is at its initial stage with further contributions expected in next few years.

We have showed that coordinated optimal operation of building climate control and available microgrid that reported cost savings of 123% (23% revenue) in the realistically set scenario [19], while the contribution of coordination itself, compared to uncoordinated and individually optimal operation of the systems, increases the savings of additional 15%. An example of integrated approach in buildings operation is shown in Fig. 1. as a hierarchical control approach to integration of several building technologies while keeping their inherent independency by achieving the interconnection only in price-consumption profiles communication. The concept is envisioned to be further extended to aggregator, district and city levels, incorporating building, transport and infrastructure areas.

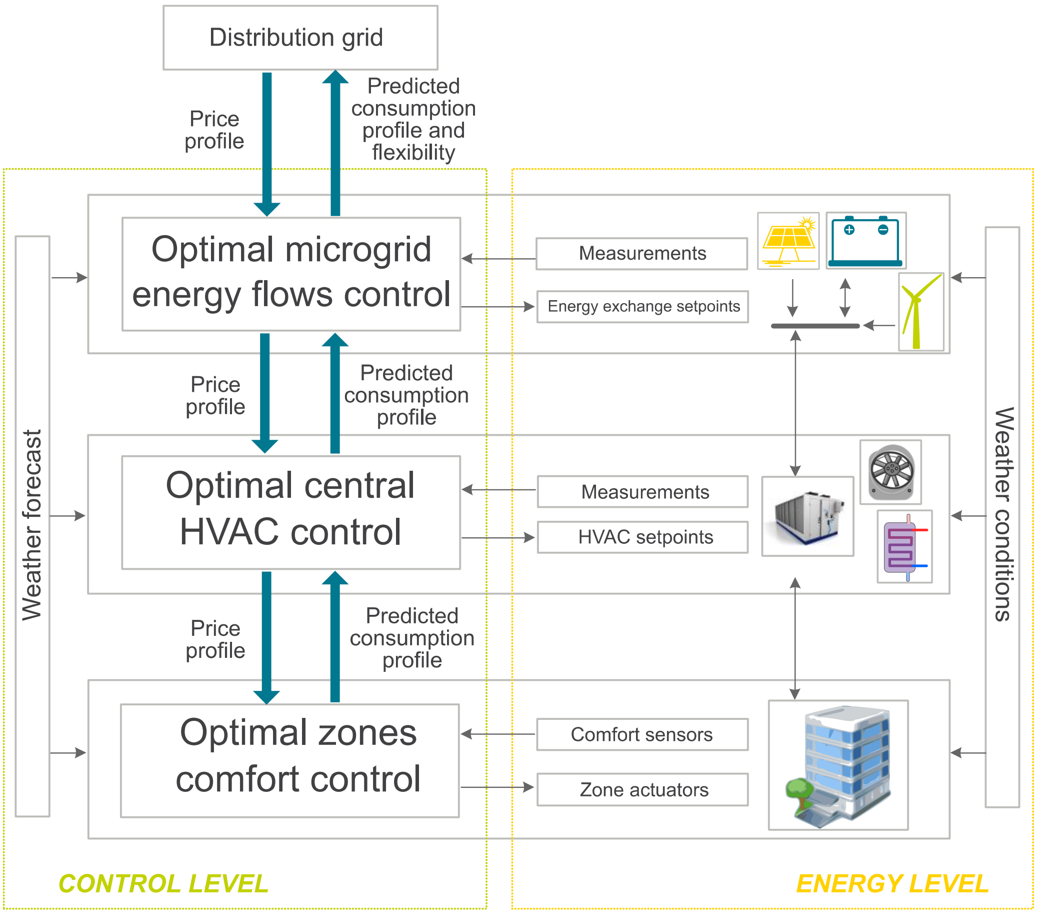

Fig. 1. Hierarchical building energy management strategy.

In parallel to buildings energy efficiency improvement, research efforts in distributed energy production and transformation of energy market to a multi-agent system with buildings as prosumers joined together in aggregators suitable for various bidding strategies and, recently, block chain approaches [20]. The topic is tightly followed by utilisation of mutable renewable power production integrated through distributed storages by means of a microgrid concept. The term smart grids is becoming an everyday whereas in the area of smart cities it is implemented through building aggregators, integration of transport and infrastructure, leading to smart districts and finally smart cities themselves. Electrical vehicles with their batteries are recognized as an additional accessible storage for building ancillary services and operation cost-effectiveness [21].

Urban railway traffic with multi-train coordination is also recognized as one of the largest possible economic factors in smart cities. Trains on-route energy consumption of a single train and show significant improvements and energy savings of up to 30% as reported in [22] and [23]. Multiple trains coordination and, furthermore, power grid conditions consideration offer even larger possibilities in better utilization of regenerative energy and reduced overall system costs. Regenerative energy utilization is efficiently exploited through optimization of timetables for synchronization of multiple trains acceleration and braking times or installation of energy storage devices for the excess energy produced by trains. Both storage employment and timetable optimization report significant savings of up to 25% [24]–[26], but consider trains traction and speed profiles as constants while there is a significant potential in their dynamic rearrangement. Integrated approaches to co-optimization of both timetables and train traction profile are therefore becoming more attractive in recent years.

A motivation for integration of all building subsystems towards the energy efficiency and cost-effectiveness increase is evident. In the invited session, we introduce an opportunity of utilizing buildings to resolve the critical issue of power imbalance in the distribution grid, integrating them to microgrids and transport through developed control methods, leading to the concept of smart cities. Buildings act as thermo-electric storage systems, trains as kinetic energy storages and electrical vehicles as electrical storages, which are identified as the main need for integration of large share of renewable energy sources [13].

B. Relevance to the conference

From the control perspective, the three main pre-requisites for further reduction in costs of operation and integration of smart city components are identified:

1. development of new system models suitable for model predictive control,
2. system optimisation and integration tools based on decentralised control,
3. implementation aspects of such control strategies in large data centres.

Proposed papers contribute to the three topics directed to realisation of the smart city vision. The topic is the cutting edge of the state-of-art in scientific research domains, tackled by world's renowned research groups, but also gaining much interest in government, industry and public domains. The obtained results prove that the model predictive control in combination to decentralised control approaches is the effective integration tool while the smart city area is one of the most suitable applications. We therefore strongly believe that the proposed invited session will bring significance to the conference.

C. Contributions

The five following papers contribute to the session with described distinctions and roles in control in smart cities:

1. Iulia Stamatescu, Stephane Ploix, Ioana Făgărășan, Grigore Stamatescu*, “Data Center Server Energy Consumption Optimisation Algorithm”
2. Hrvoje Novak*, Mario Vašak, “Energy-efficient train traction control on complex rail configurations”
3. Danko Marušić*, Vinko Lešić, Tomislav Capuder, Mario Vašak, “Price-optimal Energy Flow Control of a Building Microgrid Connected to a Smart Grid”
4. Charalampos Galatsopoulos*, Simira Papadopoulou, Chrysovalantou Ziogou, Spyros Voutetakis, "Energy Management Strategy in a Residential Battery Energy Storage System"
5. Petra Bucić*, Vinko Lešić, Mario Vašak, “Distributed Optimal Batteries Charging Control for Heterogenous Electric Vehicles Fleet”

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REFERENCES

[1] Renewable Energy Policy Network for the 21st Century (REN21), Renewables 2016, Global Status Report, 2016.

[2] F. Oldewurtel, A. Parisio, C. N. Jones, D. Gyalistras, M. Gwerder, V. Stauch, B. Lehmann, M. Morari, ”Use of Model Predictive Control and Weather Forecasts for Energy Efficient Building Climate Control”, Energy and Buildings, vol. 45, pp. 15–27, 2012.

[3] D. Sturzenegger, D. Gyalistras, M. Morari and R. S. Smith, ”Model Predictive Climate Control of a Swiss Office Building: Implementation, Results, and Cost-Benefit Analysis”, IEEE Transactions on Control Systems Technology, vol. 24, no. 1, pp. 1–12, 2016.

[4] J. Široky, F. Oldewurtel, J. Cigler, S. Privara, ”Experimental analysis of model predictive control for an energy efficient building heating system”, Applied Energy, vol. 88, no. 9, pp. 3079-3087, 2011.

[5] T. Žakula, P. R. Armstrong, L. Norford, ”Modeling environment for model predictive control of buildings”, Energy and Buildings, vol. 85, pp. 549–559, 2014.

[6] F. Tahersima, J. Stoustrup, H. Rasmussen and S. A. Meybodi, ”Economic COP Optimization of a Heat Pump with Hierarchical Model Predictive Control”, in Proc. of the 51st Conference on Decision and Control, pp. 7583–7588, 2012.

[7] F. Oldewurtel, D. Sturzenegger, G. Andersson, M. Morari and R. S. Smith, ”Towards a Standardized Building Assessment for Demand Response”, in Proc. of the 52nd Conference on Decision and Control, pp. 7083–7088, 2013.

[8] M. Brandstetter, A. Schirrer, M. Miletić, S. Henein, M. Kozek and F. Kupzog, ”Hierarchical Predictive Load Control in Smart Grids”, IEEE Transactions on Smart Grid, vol. 8, no. 1, pp. 190–199, 2017.

[9] M. Gulin, M. Vašak and M. Baotić, ”Analysis of microgrid power flow optimization with consideration of residual storages state”, in Proc. of the 2015 European Control Conference, pp. 3126–3131, 2015.

[10] D. T. Nguyen and L. B. Le, ”Optimal Bidding Strategy for Microgrids Considering Renewable Energy and Building Thermal Dynamics”, IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1608–1620, 2014.

[11] X. Xue, S. Wang, C. Yan, B. Cui, ”A fast chiller power demand response control strategy for buildings connected to smart grid”, Applied Energy, vol. 137, pp. 77–87, 2015.

[12] C. D. Korkas, S. Baldi, I. Michailidis, E. B. Kosmatopoulos, ”Occupancy-based demand response and thermal comfort optimization in microgrids with renewable energy sources and energy storage”, Applied Energy, vol. 163, pp. 93–104, 2016.

[13] A. Roskilly, P. Taylor, J. Yan, ”Energy storage systems for a low carbon future–in need of an integrated approach”, Applied Energy, vol. 137, pp. 463–466, 2015.

[14] R. Scattolini, ”Architectures for distributed and hierarchical Model Predictive Control – A review”, Journal of Process Control, vol. 19, no. 5, pp. 723–731, 2009.

[15] E. O´Dwyer, M. Cychowski, K. Kouramas and G. Lightbody, ”A Hierarchical Model-Based Predictive Control Strategy for Building Heating Systems”, in Proc. of the 25th IET Irish Signals & Systems Conference and 2014 China-Ireland International Conference on Information and Communications Technologies, pp. 298–303, 2014.

[16] P.-D. Morosan, R. Bourdais, D. Dumur, J. Buisson, ”Building temperature regulation using a distributed model predictive control”, Energy and Buildings, vol. 42, no. 9., pp. 1445-1452, 2010.

[17] S. Koehler, C. Danielson and F. Borrelli, ”A Primal-Dual Active-Set Method for Distributed Model Predictive Control”, in Proc. of the American Control Conference, Chicago, IL, USA, pp. 4759–4764, 2015.

[18] N. Parikh and S. Boyd, ”Block splitting for distributed optimization”, Mathematical Programming Computation, vol. 6, no. 1, pp. 77–102, 2014.

[19] V. Lešić, A. Martinčević, M. Vašak, ”Modular Energy Cost Optimization for Buildings with Integrated Microgrid”, Applied Energy, vol. 197, pp. 14-28, 2017.

[20] G. Cui, Y. Qin, K. Shi, L. Liu, B. Qi, B. Li, "Application of Block Chain in Multi - level Demand Response Reliable Mechanism", Proceedings of 2017 International Conference on Information Management, pp. 337-341, 2017.

[21] O. Sundstrom, C. Binding, "Flexible Charging Optimization for Electric Vehicles Considering Distribution Grid Constraints", IEEE Transactions on Smart Grid, vol. 3, no. 1, pp. 26–37, 2012

[22] Y. Wang, B. Ning, F. Cao, B. De Schutter, and T. van den Boom, “A survey on optimal trajectory planning for train operations,” Proceedings of the 2011 IEEE International Conference on Service Operations, Logistics, and Informatics (SOLI), pp. 589–594, 2011.

[23] Y. Wang, B. Ning, T. van den Boom, and B. De Schutter, Optimal Trajectory Planning and Train Scheduling for Urban Rail Transit Systems. Springer International Publishing, 2016.

[24] X. Yang, X. Li, B. Ning, and T. Tang, “A survey on energy-efficient train operation for urban rail transit,” IEEE Transactions on Intelligent Transportation Systems, vol. 17, no. 1, pp. 2–13, 2016.

[25] T. Ratniyomchai, S. Hillmansen, and P. Tricoli, “Recent developments and applications of energy storage devices in electrified railways,” Electrical Systems in Transportation, IET, 2014.

[26] S. de la Torre, A. Sanchez-Racero, J. Aguado, M. Reyes, and O. Martianez, “Optimal sizing of energy storage for regenerative braking in electric railway systems,” IEEE Transactions on Power Systems, vol. 30, no. 3, pp. 1492–1500, 2015.