

IMPROVED REAL-TIME OPERATION OF MICROGRIDS WITH INTEGRATED ECONOMIC CONSTRAINTS

M. LEGRY, F. COLAS
C. SAUDEMONT

Univ. Lille, Centrale Lille,
Arts et Métiers Paris Tech, HEI
L2EP, FRANCE

Martin.legry@ensam.eu

J.Y. DIEULOT

Polytech-Lille
CRISAL, FRANCE

Jean-yves.dieulot@polytechlille.fr

O. DUCARME

ENGIE Lab Laborelec
ENGIE, BELGIUM

Olivier.ducarme@engie.com

ABSTRACT

Microgrids control has a hierarchical structure in which an upper layer manages the economic operation on an hourly time-scale and a lower layer which deals with the real-time operation of the microgrid. This paper proposes to compare a classical shrinking horizon Model Predictive Control (MPC) for microgrid supervision with an improved scheme. The new MPC supervisor embeds a discretization of the optimal economic set points, which are provided by the upper layer, using an appropriate interpolation algorithm. This new scheme improves the coordination between the economic and real-time layers and increases the economic performances of the microgrid.

INTRODUCTION

Microgrids are considered as an efficient tool for empowering islanded communities, increasing the renewable penetration [1]. Usual control structures are hierarchical – economic optimization, real time supervisor and microgrid stability. Microgrid stability is ensured by such techniques as droop control [2]. Secondary control and nominal operation (Power Management System, PMS) are ensured by centralized or distributed supervisors. Finally, the economic supervision of the microgrid (Energy Management System, EMS) is performed with offline optimization methods, e.g. stochastic programming or heuristics based methods [3]. However, little is said how real-time supervisors should be coordinated with EMS and handle the economic references. Microgrids have to deal with short term variations in the system (load and production) and reaching the economic objectives over a short-term horizon may be difficult. The remainder of this paper will detail the microgrid supervisor and an original integration of the discretized economic reference into a Model Predictive Controller based supervisor. Then, the microgrid model, simulations and indicators will be presented to compare the method with a classical strategy.

MICROGRID SUPERVISOR

The proposed microgrid supervisor is based on the a two-

layer control technique. The upper layer is a classical optimal power flow that aims to optimize:

- the economic operation of the microgrid,
- CO2 emissions,
- lifespan of the equipment,

under:

- microgrid and equipment model limitations,
- and power balance constraint.

The offline optimization routine results in an optimal trajectory of the State of charge for each storage devices plus, possibly, the use of the Point of Common Coupling (PCC). In the later, the microgrid is islanded and the PCC is not considered as lever. The second layer purpose is to drive each equipment to match as close as possible the optimal trajectory, subject to the disturbances and the deviations from the forecasts. In contrast to classical ones, the supervisor is divided in two-time scales and therefore offer the possibility to integer in the faster a refined model of the network and to manage the voltage and frequency of the microgrid. This layer is developed using a Model Predictive Control technique [4]. The synoptic of the MPC technique is represented in Figure 1. From the results of the upper layer, the objective to be minimized is formulated as follows:

$$\min J = \sum_{k=0}^{N_c} (x_{predicted} - x_{reference})^2 + \sum_{k=0}^{N_c} \beta \cdot C_{startup}$$

where the first term represents the error between the SoC targets and the SoC reached by the lower layer, $C_{startup}$ is the cost of starting the genset, and β accounts for an unplanned start-up of the generator lever highly penalized.

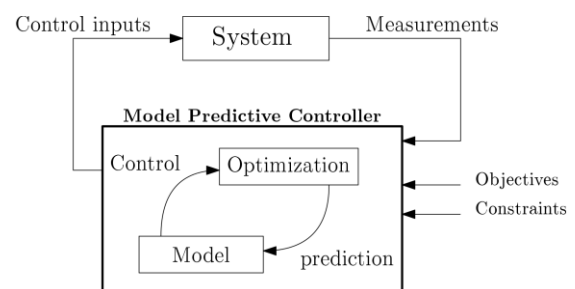


Figure 1: Model Predictive Controller synoptic

The additional constraints are the microgrid network model and the constraints and model related to the voltage and frequency such as droop converters. In order to include them into the prediction model, the proposed MPC uses a linearized model of the network based on power flow equations [5]:

$$P_i^{gen} - P_i^{load} = \sum_{j=1}^N |Y_{ij}| |V_j| |V_i| \cos(\delta_i - \delta_j - \theta_{ij})$$

$$Q_i^{gen} - Q_i^{load} = \sum_{j=1}^N |Y_{ij}| |V_j| |V_i| \sin(\delta_i - \delta_j - \theta_{ij})$$

In which, $|V_j|$, $|V_i|$, δ_i , δ_j are the voltage magnitude and angle resp., $|Y_{ij}|$ and θ_{ij} are the admittance matrix magnitude and angle resp. The linearized equations results:

$$\Delta P_i = \frac{\partial P_i}{\partial V} \Delta V + \frac{\partial P_i}{\partial \delta} \Delta \delta + \frac{\partial P_i}{\partial \omega} \Delta \omega$$

$$\Delta Q_i = \frac{\partial Q_i}{\partial V} \Delta V + \frac{\partial Q_i}{\partial \delta} \Delta \delta + \frac{\partial Q_i}{\partial \omega} \Delta \omega$$

The compact discrete model of the network is as follows:

$$\begin{bmatrix} \Delta V_1(k+1) \\ \vdots \\ \Delta V_i(k+1) \\ \Delta \delta_2(k+1) \\ \vdots \\ \Delta \delta_i(k+1) \\ \Delta \omega(k+1) \end{bmatrix} = \begin{bmatrix} \frac{\partial P_i}{\partial V} & \frac{\partial P_i}{\partial \delta} & \frac{\partial P_i}{\partial \omega} \\ \frac{\partial Q_i}{\partial V} & \frac{\partial Q_i}{\partial \delta} & \frac{\partial Q_i}{\partial \omega} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_1^*(k) \\ \vdots \\ \Delta P_i^*(k) \\ \Delta Q_1^*(k) \\ \vdots \\ \Delta Q_i^*(k) \end{bmatrix}$$

The matrices are updated with each new economical set points calculated from the upper layer and are completed with the voltage and frequency maximum deviations (5 and 10 percent resp.) to form a discrete linearized model:

$$X(k+1) = A.X(k) + M.\Delta u(k) + C.\Delta d(k) \quad (1)$$

With X, the concatenation of the State of Charge of each storage devices, the voltage, and angle of each node, the active and reactive power references for the controlled equipment and the generated active and reactive power at each node. Δu and Δd are the changes in power references and power disturbances respectively. The matrices A, M and C are defined from the previous equations of the network, equipment and droop models.

Finally, the supervisor answers the following optimization problem:

$$\min_{\Delta u} J = \sum_{k=0}^{N_c} |x_{predicted} - x_{reference}| + \sum_{k=0}^{N_c} \beta.C_{startup} \quad (2)$$

Subject to (1) and the equipment and network limits.

INTEGRATION SCHEME

Classical two-layer microgrid supervisor relies on a shrinking horizon for the faster controller. A direct drawback of such a strategy is that the effort is much greater for any disturbances at the end of the control horizon (see Figure 2). To overcome this issue, we propose a shrinking horizon for both layer. The challenge in such a strategy is the synchronisation of the references for the moving windows of the faster layer. For each faster timestep, we define the reference as an interpolation of the upper layer references. Two methods can be used for obtaining the discrete references: a stair-based and a linear-based interpolation (see Figure 3).

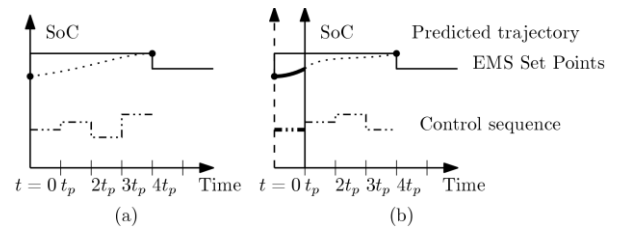


Figure 2: Conventional stair-based shrinking MPC supervisor (a) initial state of the system and control sequence – (b) control sequence and predicted trajectory at $t = t_p$

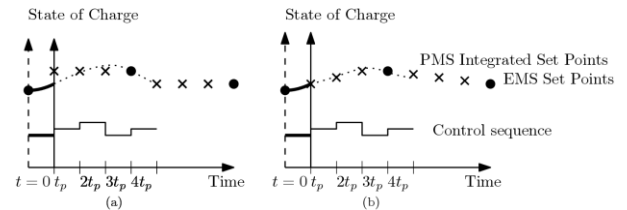


Figure 3: Proposed strategies - (a) with constant references - (b) with linear interpolated references

Finally, the strategy to project the upper layer reference into the faster controller is summarize in the Algorithm 1 and is repeated at each new calculation of the optimal trajectory. In the later, we use the linear interpolation methods for the rolling horizon supervisor.

ALGORITHM

Initialization

Update microgrid measurements and model,

$$t_e = \alpha t_p,$$

$$t = 1,$$

Routine

1. Collect economic set points
2. For the next PMS control horizon,
 - if $t \bmod t_e = 0$, update EMS interpolated set points.
 - 1.1. Make the discretization for each EMS timeslot considered,
 - 1.2. Update the PMS energy trajectory.
3. Solve MPC routine
4. Apply control sequence
5. $t = t + 1$

Algorithm 1: Integration of economic set points into microgrid supervisor

RESULTS

The simulations are performed using the Matlab toolbox YALMIP [6]. The PV and load forecasts are based on real measurement with different sampling times and scaled to fit a 100kW base power microgrid.

The test case is composed of three nodes with:

- Node 1: 100 kW / 300 kWh energy storage,
- Node 2: 100 kW diesel generator, and 25 kW load
- Node 3: 100 kW PV plan.

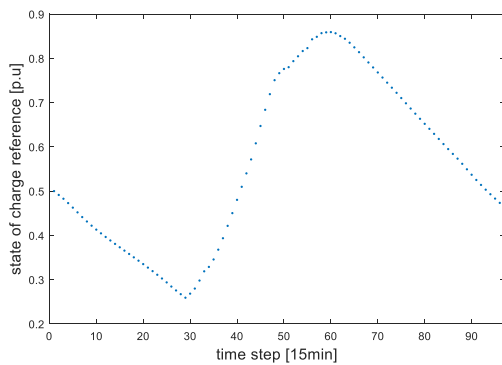


Figure 4: State of charge reference trajectory from the economic optimization

From the calculated trajectory represented in Figure 4, the power profiles with the shrinking horizon supervisor are in the next figure.

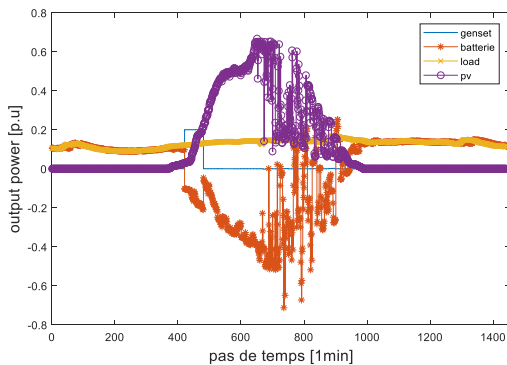


Figure 5: Power profile from the shrinking horizon-based Power Management System

Figure 6 displays the power profiles for a rolling horizon supervisor.

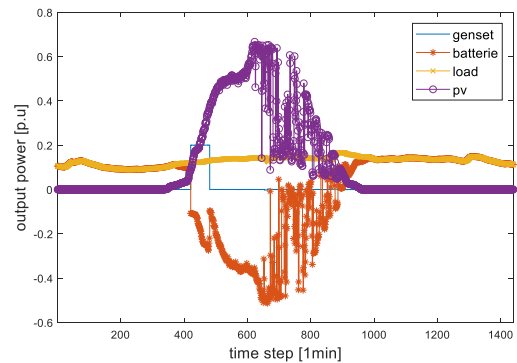


Figure 6: Power profile from the rolling horizon-based Power Management System

To compare both strategy, it is worth focusing on a large change in references such as the step down of the diesel generator. Figure 7 at the bottom display the behaviour of the rolling horizon strategy for this time step. It can be observed that the transition is smoothed between the time step 460 and 481, while the genset output power goes from 0.2 to 0 p.u at $t = 481$.

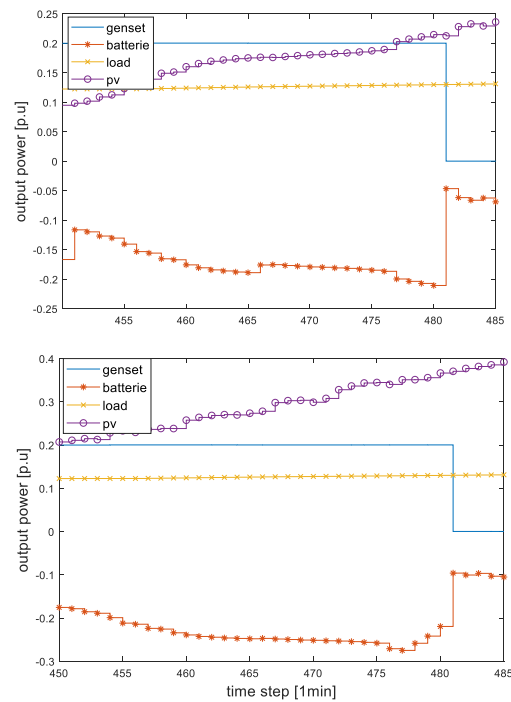


Figure 7: Power profile – focus on large change in genset output power. Top: shrinking horizon, bottom: rolling horizon

From these figures, the tracking performance is similar with a final error of the State of Charge planned at the end of the day by the EMS of 0.2% and 1.2% for the rolling and shrinking horizon respectively. Comparing the voltage and frequency deviations (see Figure 8), the second strategy is more robust to the load and

photovoltaic forecast errors and the voltage and frequency deviation are minimize compared to the shrinking horizon.

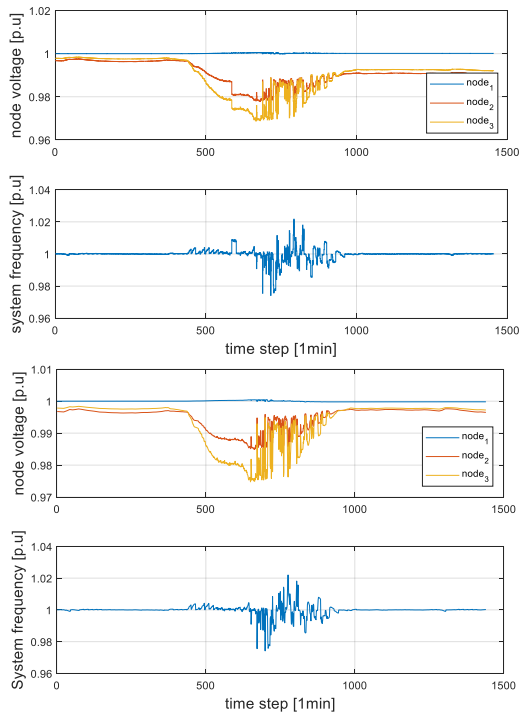


Figure 8: Voltage and frequency profile for both strategies. Top: shrinking horizon, bottom: rolling horizon

CONCLUSION

The proposed strategy integrates a rolling horizon for the lower layer in opposition to conventional shrinking horizon. This layer requires then a discretisation of the reference trajectory. The simulations showed that the rolling horizon induces an anticipation of the system. It is expected that this may lead to undesired voltage and frequency deviations that further simulations and more complex load and production profiles may bring to light.

REFERENCES

- [1] "About Microgrids." [Online]. Available: <https://building-microgrid.lbl.gov/about-microgrids-0>.
- [2] H. Han, X. Hou, J. Yang, J. Wu, M. Su, and J. M. Guerrero, "Review of power sharing control strategies for islanding operation of AC microgrids," *IEEE Transactions on Smart Grid*, vol. 7, no. 1, pp. 200–215, 2016.
- [3] L. I. Minchala-Avila, L. E. Garza-Castañón, A. Vargas-Martínez, and Y. Zhang, "A review of optimal control techniques applied to the energy management and control of microgrids," in *Procedia Computer Science*, 2015, vol. 52, no. 1, pp. 780–787.
- [4] E. F. Camacho and C. Bordons, *Model Predictive Controllers*. 2007.
- [5] P. Kundur, *Power system control and stability*. New York: McGraw, 1994.
- [6] J. Lofberg, "YALMIP: a toolbox for modeling and optimization in MATLAB," in *2004 IEEE International Conference on Robotics and Automation*, 2004, pp. 284–289.