PROJET ODRI - AXE 5

Offre de Raccordement Intelligente

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1 Voltage Rise control Block scheme

To control the voltage rise on the higher voltage buses, the following block scheme is developed.

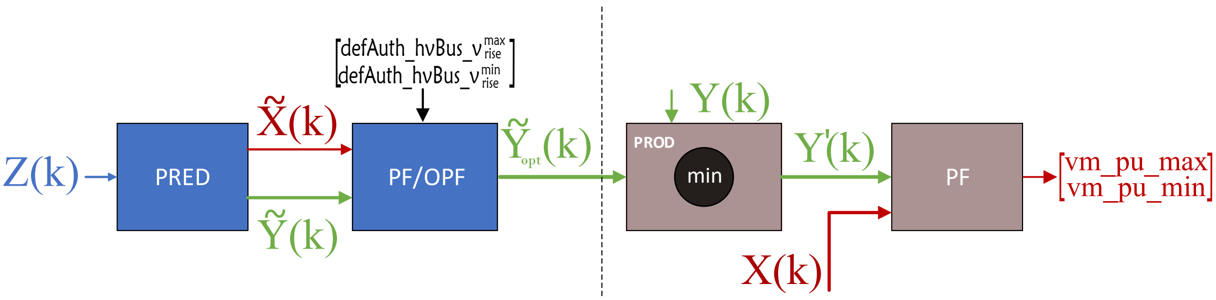

Figure 1: Voltage Rise control Block scheme

Blocks in blue and grey respectively implement algorithms computed before and after the reality of all the variables is unveiled.

1.1 Variables definition

The variables involved are defined as follows:

$$Y(k) = \begin{bmatrix} P0_1(k) \\ \vdots \\ P0_{m_{HT}}(k) \end{bmatrix}, \quad X(k) = \begin{bmatrix} P_{load}(k) \\ P^{BT}(k) = \begin{bmatrix} P0_1(k) \\ \vdots \\ P0_{n_{BT}}(k) \end{bmatrix} \\ P^{HT}(k) = \begin{bmatrix} P0_1(k) \\ \vdots \\ P0_{n_{HT}}(k) \end{bmatrix} \end{bmatrix}, \quad Z(k) = \begin{bmatrix} [X(k-1)^T, \ Y(k-1)^T] \\ \vdots \\ [X(k-N)^T, \ Y(k-N)^T] \end{bmatrix}$$

where :

- $Y(k) \in \mathbb{R}^{m_{HT}}$ is the active power produced by all controllable static generators at period k;

- $\tilde{Y}(k)$ the predicted value of $Y(k)$;
- $\tilde{Y}_{opt}(k)$ the optimal predicted value of $Y(k)$ to respect the voltage rise constraints in the network or the active power demanded by the GRD to the static generators;
- $Y^{'}(k)$ is the actual active power injected into the grid.
- $X(k) \in \mathbb{R}^{(n_{HT}+n_{BT}+1)}$ is the active power produced by the uncontrollable higher and lower voltage generators and the load demand at period k;
- $\tilde{X}(k)$ is the predicted value of $X(k)$
- $Z(k) \in \mathbb{R}^{N*2}$ with N being the total number of past periods or lag is the history of the considered network.

1.2 Algorithms

The algorithms implemented by each block are as follows:

- **PRED**: Prediction. All the prediction algorithms would be implemented here;
- **PF/OPF**: Run power flow and, if needed, optimal power flow.
- **PROD**: Implement a physical constraint. The controllable static generator cannot output more than what is produced at a certain period.
- **PF**: Run a power

1.3 Principle of operation

Lets us divide each instant k into two distinct parts: before (Blue blocks) and after (grey blocks), a command is sent to the controlled HV(s) generator(s). This can also be considered as before and after the unknown variables are reveiled.

1.3.1 Before

The prediction block **PRED** receives an history of the electrical network as $Z(k)$. The history is used to produce both $\tilde{X}(k)$ and $\tilde{Y}(k)$, which are sent to the **PF/OPF** block. Inside this block, a power flow is always executed based on the predicted variables entering. Let $v_{rise}^{max}(k)$ and $v_{rise}^{min}(k)$ be the resulting maximum and minimum voltage detected on the electrical network Hv buses.

Two cases are possibles:

- All voltage rise constraints are respected i.e., $v_{rise}^{max}(k)$ and $v_{rise}^{min}(k)$ are lower and greater than the defined thresholds $defAuth\_hvBus\_v_{rise}^{max}$ and $defAuth\_hvBus\_v_{rise}^{min}$

$$v_{rise}^{max} \leq defAuth\_hvBus\_v_{rise}^{max}$$
$$v_{rise}^{min} \geq defAuth\_hvBus\_v_{rise}^{min},$$

  PF/OPF outputs $\tilde{Y}_{opt}(k) = \tilde{Y}(k)$

- Either of voltage rise constraints is not respected i.e.

$$v_{rise}^{max} \geq defAuth\_hvBus\_v_{rise}^{max}$$
$$v_{rise}^{min} \leq defAuth\_hvBus\_v_{rise}^{min},$$

  an optimal power flow is executed to find the optimal value(s) $\tilde{Y}_{opt}$ of the controllable Hv generator respecting these thresholds.

In both cases, the optimal $\tilde{Y}_{opt}$ is sent to the Hv controlled Producers.

1.3.2 After

The block **PROD** at the controllable producers end receives a command $\tilde{Y}_{opt}$ of active power to inject into the electrical grid to satisfy the defined threshold. A minimum operation is defined as

$$Y'(k) = min\Big(\tilde{Y}_{opt}(k), Y(k)\Big)$$

implements a physical constraint, i.e. a controllable generator cannot inject more than what is produced at a certain period into the electrical grid.

The block **PF** receives the actual active power injected by the controllable Hv(s) generator(s), i.e. $Y'(k)$, by the uncontrollable higher and lower voltage generators and the load demand, i.e. $X'(k)$. Based on these inputs, a power flow is executed to provide outputs to the user to verify the control implemented effects into the whole process.

2 Robust Voltage Rise control Block scheme

Following the principle of operation described in the previous section, at each instant, the controllable Hv(s) generator(s) will receive a control command $\tilde{Y}_{opt}(k)$ whether or not an exceeding (lower or upper) of the authorised voltage rise occurs. This strategy is not optimal for the GRD or the Hv(s) producer. We developed the Robust Voltage Rise control Block scheme to mitigate this problem.

The new method's robustness consists of only sending a control command to the Hv(s) producer when a violation of the authorised voltage rise is predicted in the block PF/OPF. On the contrary, when the constraints are respected, no command is sent to the controlled Hv(s) producer(s) that can therefore inject all their produced power $Y(k)$ onto the electrical grid.

3 Combined RNN prediction

To improve the predictions when using an RNN in the block **PRED**, we alter the robust Voltage rise control block scheme described in Figure 1. The changes summarized by Figure 2 and 3 focus mainly on the **before** part of the principle of operation described in section 1.3.1.

3.1 RNN models description

The three models presented in figure 2 are described in the following section.

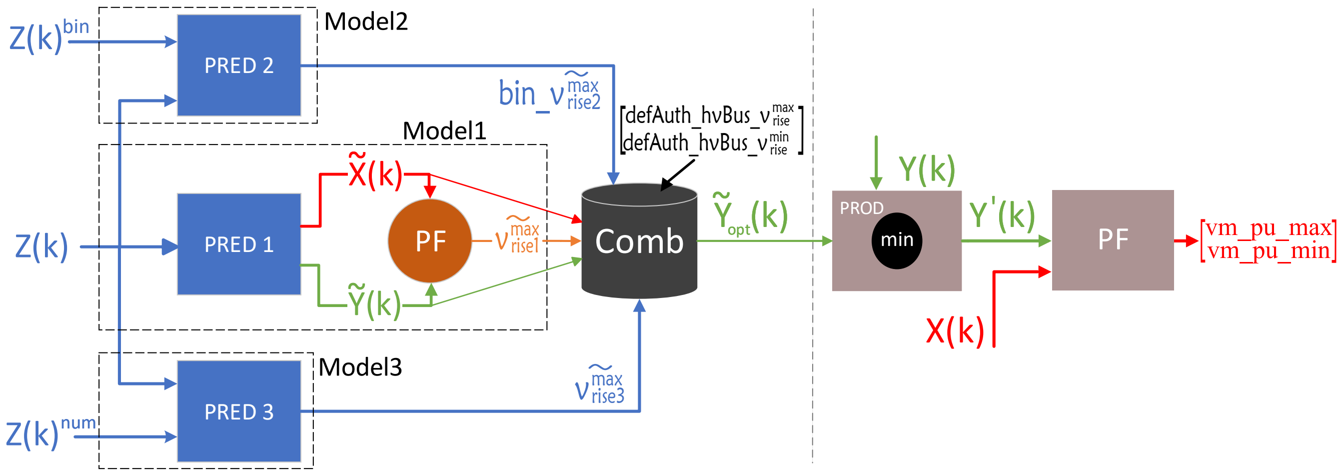

Figure 2: Robust Combined RNN block Scheme

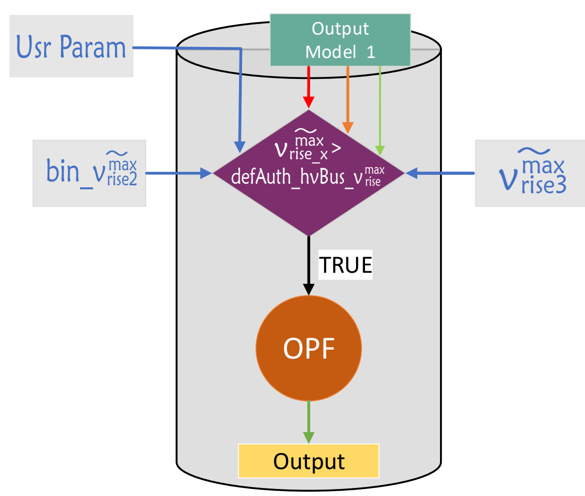

Figure 3: Inside Comb block of Robust Combined RNN block Scheme

3.2 Model1

The Prediction block **PRED 1** is an RNN which predicts $\tilde{X}(K)$ and $\tilde{Y}(k)$ based on a finite history $Z(k)$ of the system. The predicted variables are sent to the block **PF** that computes a power flow and returns $\widetilde{V^{max}_{rise1}}$ the predicted value of the maximum voltage rise on the buses. All the predicted variables are sent to the block **Comb**.

3.3 Model2

The Prediction block **PRED 2** is an RNN which, based on $Z(k)$ and $Z(k)^{bin}$ predicts whether an exceeding of the predefined authorized voltage rise $defAuth\_hvBus\_v^{max}_{rise}$ will occur or not. Note that $Z(k)^{bin}$ is a binary history, i.e. a vector filled with 0 and 1 such that :

- 1 : An exceeding of $defAuth\_hvBus\_v^{max}_{rise}$ occurred at the concerned period
- 0 : The $defAuth\_hvBus\_v^{max}_{rise}$ threshold is respected at the concerned period.

The model outputs $\widetilde{bin\_v^{max}_{rise}}$ that is sent to the block **Comb**

3.4 Model3

The Prediction block **PRED 3** is an RNN which, based on $Z(k)$ and $Z(k)^{num}$ predicts $\widetilde{v^{max}_{rise3}}$ the predicted value of the maximum voltage rise that will occur in the next period. Note that $Z(k)^{num}$ is a numerical history, i.e. a vector filled with the vm_pu_max the actual maximum voltage rise detected on the network after implementing the control strategy at the previous instants.

3.5 Combined RNN models

The outputs of the previously described models added to a user parameter *Usr Param* enter the block **Comb**, which depending on the case, based on the predicted variables of Model 1 $\tilde{X}(k)$ and $\tilde{Y}(k)$) must perform an Optimal Power flow (OPF).

The possible values of *Usr Param* help to choose among one or a combination of the different prediction models to perform an OPF are the following:

$$Usr\ Param = \begin{cases} \text{Model 1, run OPF when} & \widetilde{v^{max}_{rise1}} > defAuth\_hvBus\_v^{max}_{rise} \\ \text{Model 2, run OPF when} & bin\_\widetilde{v^{max}_{rise2}} = 1 \\ \text{Model 3, run OPF when} & \widetilde{v^{max}_{rise3}} > defAuth\_hvBus\_v^{max}_{rise} \\ \quad \text{AtL 1, run OPF when} & \widetilde{v^{max}_{rise\_x}} > defAuth\_hvBus\_v^{max}_{rise} \text{ for at least one of the models.} \\ \quad \text{AtL 1, run OPF when} & \widetilde{v^{max}_{rise\_x}} > defAuth\_hvBus\_v^{max}_{rise} \text{ for at least two of the models.} \\ \quad \text{AtL 3, run OPF when} & \widetilde{v^{max}_{rise\_x}} > defAuth\_hvBus\_v^{max}_{rise} \text{ for all the three models.} \end{cases}$$

4 Implementation

To implement the process described by any of the previous block scheme, we propose two solution, namely the *pure* and *degraded closed loop*, of which the latter has been implemented in all the developed notebooks. The following lines explain both implementations.

4.1 Pure closed Loop

In this case, the information in the system at time k moves from block A to the following block B and so up to the last block, which in turn sends its output information back to the first block. The exact process is repeated for each period of the simulation length.

4.2 Degraded closed Loop

Given that for the first block **PRED** the whole dataset is available (by whole dataset, we mean the dataset associated with all the period of the simulation length), here, each block receives as input the full dataset, performs its intended operations and then send the whole output to the next block.

In the different notebooks, we have implemented the *Degraded closed Loop* since the it has been shown to be the fastest and facilitates debugging. We emphasis that in real time the *pure closed loop* will be implemented since all the data reveals after each period.