Consider the problem of voltage stability control and reactive power scheduling in a multi-area power system (possibly) controlled by independent transmission system operators. A major issue is to coordinate, with a high level of robustness, the control actions of the interconnected areas with respect to their operational objectives and constraints. We propose an agent-based cooperative approach to this issue. Each control area is treated as an intelligent agent that pursues small-scale, self-owned objectives, assuming that each area is capable to properly communicate with its own entities and to stably govern them in a centralized or decentralized manner. It is shown that while each agent pursues its local goals, the multi-agent control scheme stabilizes the large-scale system and achieves the global goals of an adaptive voltage control function through neighborhood active interactions.

Centralized Coordination: Each TSO (Transmission System Operator) transfers its prerogatives to a center which builds consensus among different areas through a specific multi-party optimization scheme.
- With ever larger area of interconnected operators, this formulation is neither feasible in computation nor reliable in communication.
- Every TSO may preserve some prerogatives of its power system.

Decentralized Coordination:
- With no information exchange between TSOs, each control area assumes an external network equivalent in place of its neighbor areas and optimizes its own objective function regardless of the impact on the others.
- It does not lead to an optimal performance in large and cannot guarantee a secure operation, as satisfying the objective of a single TSO may adversely affect other TSOs.
- Conflicting local strategies reduces TSOs’ performance.

Negotiation makes our multi-agent design distinct from a conventional decentralized scheme. Intelligent agents do not respond to predefined requests from specific agents, but they negotiate and interact in a cooperative manner to reach a fair agreement.
- Adaptation, Optimization, Reconfiguration, Fault tolerance
- Extra degree of uncertainty is introduced by negotiation due to general difficulty of predicting the future state of an agent to guarantee a real-time performance.

Distributed model predictive control is used in which each agent knows a local model of its own area as well as reduced-order quasi-steady-state approximations of its neighbor areas. Action interaction-based distributed control approaches are highly promising in the light of access to wide-area synchronized PMUs and resilient high-speed communication networks in the future smart grid.

A large-scale multi-area power system is represented by an undirected graph

Communication enables the agent to negotiate with other agents for the coordinated execution of proper tasks.

Sensors perceive local data and estimate the voltage level and reactive power generation within the TSO.

Actuators execute the tasks by sending commands to taps positions, FACTS devices, shunt capacitors, and/or load shedding procedures.

Decision making evaluates the current operating state using endogenous data from the sensors and exogenous data from neighbor areas.

Control strategies provide the decision making module with a proper control and optimization algorithm from its database, based on the system operating state.

Adaptation: As long as the control strategy has not changed, the decision making module dynamically adjusts its behavior in accordance with the information provided by the sensors and communication modules. Meanwhile, the adaptation module continuously evaluates the control policy performance and accordingly updates the model parameters and objective functions in the control strategies data-base.

Normal Mode Operation based on Distributed Model Predictive Control approach

In a steady-state practice, each TSO uses a general dynamic model of its own area as well as a reduced-order QSS model of its neighbors, exchanged at each time-slot.

Every time-step k, the continuous-time linearization of local DAE equations is obtained in the “decision making” module.

\[ X_i(k+1) = A_i X_i(k) + \sum_{j=1}^{m} A_{ij} X_j(k) + B_i U_i(k) + g_i \]

\[ y_i(k) = C_i X_i(k) + \sum_{j=1}^{m} D_{ij} U_j(k-l) + h_i \]

This discrete-time approximation is employed as a prediction model in:

\[ \min J_i(X_i(k), U_i(k)) \]

Subject to:
- 1) equality constraints (1)
- 2) inequality constraints on the inputs

This performance index represents the measure of the difference between the predicted control and the desired future behavior: The lower the value, the better the performance.

Coordination in Emergency Mode Operation based on Contract Net Protocol (CNP)

In emergency resulting from a large disturbance, it is necessary to manage a fast, dynamic response for providing the bus where voltage violation occurs with reactive power support. The TSO first makes its own decision to change the settings of its own devices and agents. The TSO waits for the next time-step to repeat this process. Each agent uses the predictions of neighbor agents at the previous time-step to estimate the influence of neighbor TSOs.

Communication starts from the TSOs that will provide help for solving the problem through a bidding and contract application.