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Coordination of Multiple Voltage Controllers of Adjacent Wind Plants through Integrated Multi-Plant Coordination Function

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ABSTRACT

As the number of wind plants interconnected to the electrical grid continues to increase, so do the challenges associated with coordinating multiple wind plants. The negative impacts of not properly coordinating multiple wind plants affect both the plant owner and the system operator and will become more pronounced. A discussion of the coordination challenges, the impacts, and an active coordination solution called Multi-Plant Coordination (MPC) are discussed in detail in this paper.

Index Terms: *Voltage control, multi-plant coordination, wind power generation*

1 INTRODUCTION

Wind power generation is significantly increasing its participation in the Brazilian electrical system. The regions with the highest concentration of wind plants are the Northeast and South regions of Brazil, where the wind conditions are very attractive for wind power generation. However, the existing transmission network may not be appropriate to connect this highly increased generation. Stability challenges may arise, and because of this, the power transfer may be limited to a level below the transmission lines thermal limits.

In order to avoid voltage instabilities in these regions, the wind plants are requested to contribute reactive power to the grid and operate in voltage control mode. Typically the biggest wind generation regions in Brazil have individual voltage controllers for each plant, which typically has a maximum size of 30 MW installed capacity, resulting in multiple wind plants often connecting to the system in close electrical proximity. For example, in Igaporã region in the state of Bahia, there are nearly 30 wind plant controllers operating in electrical proximity. The large number of individual wind plants and their respective plant controllers is not necessary from a technical standpoint. Alternatively, voltage regulation of the same installed capacity of wind power could be achieved by using fewer plant controllers on fewer, larger individual wind plants. The tendency to install many small individual wind plants evolved not because of technical reasons, but due to transmission line usage incentives given to wind plant entities up to 30 MW installed capacity. A new Brazilian law, number 13.203, was established in December 8th 2015, extending the incentives to wind plant entities up to 300 MW installed capacity [1]. It is expected that the wind plant entities will be registered with a higher MW capacity, and fewer plant controllers will be installed in close electrical proximity. However, the existing projects, and still future ones connecting in the same regions, face the challenges of coordinating several voltage controllers. Anywhere that two or more voltage controllers are in electrical proximity, coordination is needed to efficiently share the reactive power contribution.

With multiple wind plants connecting at same or electrically close POIs, one interaction challenge is voltage/reactive power regulation including unbalanced reactive power sharing between wind plants where one wind plant supplies reactive power while another wind plant in the vicinity consumes it, also referred to as “fighting,” which will be discussed in greater detail.

GE’s wind plant controller known as WindCONTROL has features like voltage droop, which can reduce the “fighting” that typically occurs between closely connected plants. However, not all wind plants (including ones with non-GE turbines) and areas can be corrected with the passive voltage droop feature, especially as transmission operators become more demanding on the accuracy of voltage regulation.

This work describes at a high level the concept of multiple wind plant coordination (MPC), which utilizes a hierarchical control strategy and direct measurement and communication to and from the point of regulation (POR) to improve reactive power sharing among wind farms, simplify the operation of multiple wind plants, and other benefits that will be discussed.

2 CHALLENGES

As the density of wind plant projects increases, especially in geographic areas best suited to wind power production, instances of reactive power imbalances may become more prevalent. Reactive power imbalance between two or more power generating plants is not a new phenomenon. Anytime two or more generators are connected to a common network and operate in voltage regulation mode, there is typically some imbalance between the plants as some plants carry more of the reactive power load than others, even on a per unit basis. In cases where two or more plants have a small impedance between them and may be considered “electrically close,” the imbalance can be extreme and is often termed “fighting,” as shown in Figure 1. In this example, WF1 and WF2 are working against each other and each wind farm carrying significant amounts of reactive current, but little of that current is supporting the grid.

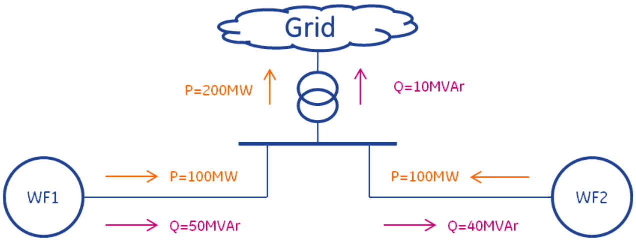

Figure 1: Illustration of "fighting" or severe imbalance of reactive power contributions

As each plant usually regulates its own bus voltage, a small impedance between plants equates to two or more plants attempting to regulate the same bus voltage. Any difference in the input and/or feedback to the voltage regulators at each plant will cause an imbalance in reactive power. Even if each plant has the exact same voltage reference set-point, it is almost certain that the measured voltages (feedback) will be different from plant to plant given the non-zero tolerance of the potential transformers or voltage measurement devices. Even for a very small difference in values, the integrator action of the voltage regulators will cause small differences to accumulate until a limit is reached at one or more of the plants. The limit most often encountered first is a reactive power capability limit. An example is shown in Figure 1 if it is considered that WF1 and WF2 are identical plants, each with a reactive capability limit of +/- 50 MVAr, where WF1 is stuck at its reactive capability limit.

“Fighting” is not specific to a particular type of generating plant. Any generating unit operating in voltage regulation mode could experience this. However, it is less common on large thermal units because the exciter regulates the voltage at the generator stator terminals, which are separated from the grid and any other generator by the impedance of the generator step-up (GSU) transformer. The GSU allows for a voltage drop between the regulated bus on the generator side and the next nearest regulated bus, which may be at an adjacent generator separated by yet another GSU or another bus on the grid. This is a form of passive coordination, which can be effective, but has significant limitations, which will be discussed.

Wind turbine generator plants typically regulate voltage at their substation bus. If the regulated substation bus is “electrically close” to other voltage-regulated buses, then “fighting” or a severe reactive power imbalance among plants may occur, degrading the performance of the wind plants and contributing to additional losses, as discussed in the following section.

3 IMPACT

A reactive power imbalance or “fighting” is undesirable from the perspective of both the transmission operator and the generating plant owner. From the grid perspective, the net reactive capability of the generating plants is reduced as one or more plants may already be at their reactive capability limit and therefore be unable to respond in one direction (either sinking or sourcing VArs). This limits the ability of the plants to respond to grid events that demand reactive power like faults, thereby reducing the system’s margin to voltage collapse.

A reactive power imbalance causes unnecessary currents to flow in the system and in the wind plant equipment. This additional current contributes to additional losses in the collector and transmission system, reducing the useable power generated by the wind plant.

The additional reactive current flows can also negatively affect the equipment in the wind plants through additional heating of the current-carrying conductors, transformers, and power electronics. That heating increases the temperature of the insulation material, which can contribute to reduce life and increased maintenance costs for the plant owner. The next section introduces several approaches for mitigating the negative impacts of “fighting.”

4 APPROACHES

Coordination of closely interconnected plants can reduce or eliminate reactive power imbalance and mitigate the negative consequences of the imbalance. There are several existing methods for coordinating plants, and they fall in two general categories: passive and active coordination.

Passive coordination does not require inter-plant communication links, but instead the coordination feature is built into the design of each plant and/or plant controls. As is common with large thermal generators, the passive coordination is due to the presence of the GSU. The GSU's impedance inserts electrical distance between the generator's terminals, where voltage is regulated, and the next closest voltage-regulated bus.

Another method of passive coordination that is common on wind farms is achieved by the use of voltage droop. Voltage droop is a feature in the wind plant controller that inserts a virtual impedance at the wind plant where no physical impedance (like a transformer) actually exists. The virtual impedance has the same effect that a GSU would, increasing the electrical distance between the voltage-regulated bus of the wind plant and the next nearest voltage-regulated bus.

Passive coordination, whether using a physical impedance like a transformer or a virtual impedance like a voltage droop feature, can be effective at reducing the reactive power imbalance. However, some reactive power imbalance will always remain, leading to unnecessary losses, heating, and wear.

Another limitation of passive coordination is that the plants are not able to control the local grid voltage accurately. By separating the regulated bus voltage of the plant from the grid by an impedance, the grid voltage is more likely to fluctuate with changing power flows, even while the plant's regulated voltage remains fixed. This limitation may be felt acutely by the transmission operator, which must maintain tight regulation of its bus voltages in order to maintain system stability and reliability.

Active coordination can not only eliminate reactive power imbalance among plants, but can simultaneously regulate the voltage at an upstream transmission system bus. Active coordination has existed in the industry for some time in a manual fashion in which the transmission operator would telephone the major generation facilities to request adjustments in reactive power via moving the voltage set-point. With the proliferation of many smaller plants, manual operation would be impractical. MPC is an automated method for active control.

While there are several methods available for improving reactive power balancing among plants, the traditional passive methods like voltage droop are not suitable for applications where many plants are interconnected to a weak electrical grid. In such applications, MPC offers a performance and operability benefit that far exceeds methods like voltage droop.

5 MPC SOLUTION WITH CASE STUDY

5.1 The MPC concept

The schematic below shows the basic functioning of the MPC scheme, which is a feature that is implemented on the GE WindCONTROL platform. The goal is to regulate the voltage at a point upstream (POR bus shown in Figure 2) with multiple wind plants in a way such that the reactive power is balanced between them.

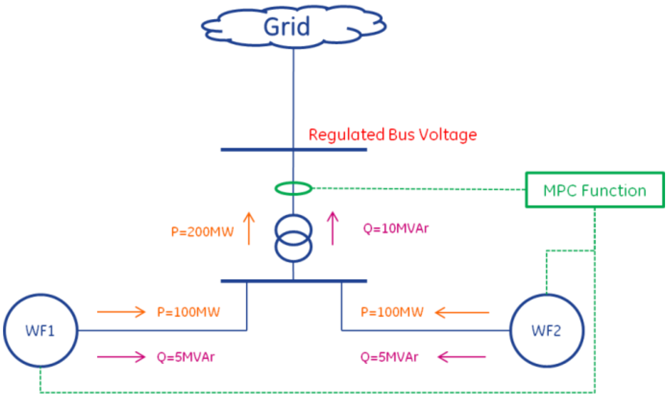

Figure 2 - MPC Schematic

5.2 Performance

The MPC concept has been implemented and tested on a system with three wind plants connected in a configuration shown in Figure 3.

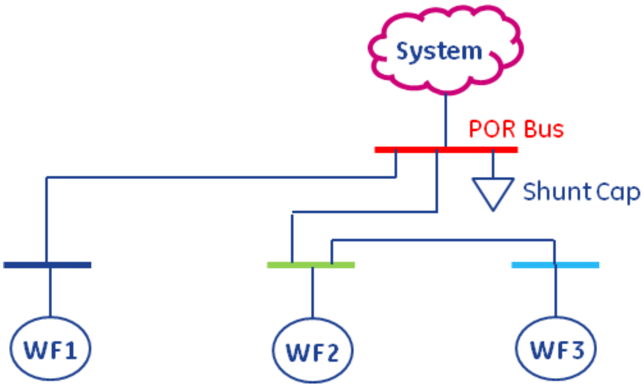

Figure 3 - Example Multi-Plant Application

Each wind plant is responsible for regulating the voltage at a point upstream of it, in a way that VArs are balanced in between wind plants and no "fighting" occurs between them. The figures below show the performance of the system with only droop (no MPC) and with MPC.

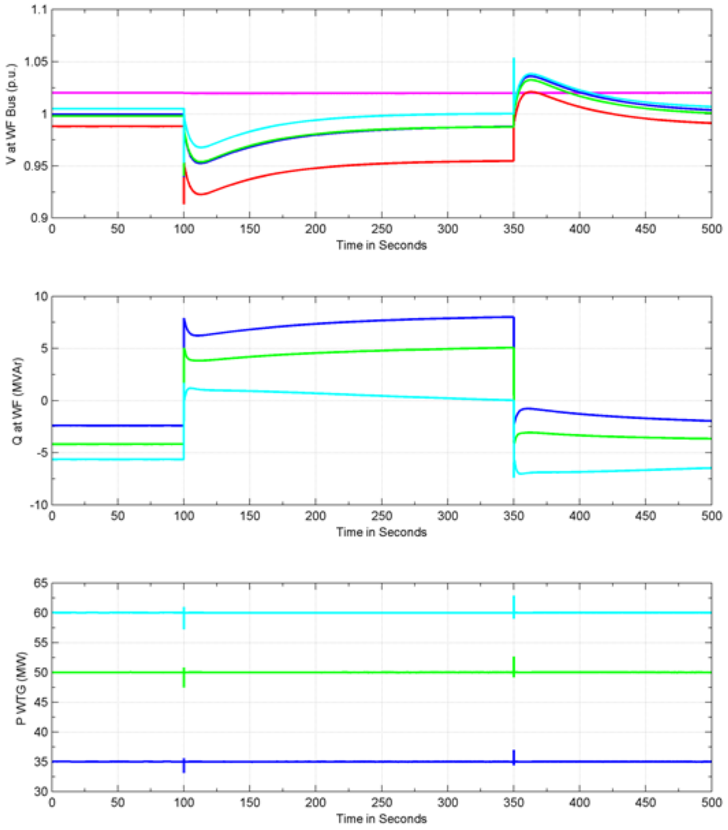

Figure 4 – Response to Shunt Capacitor Switching with Droop Only

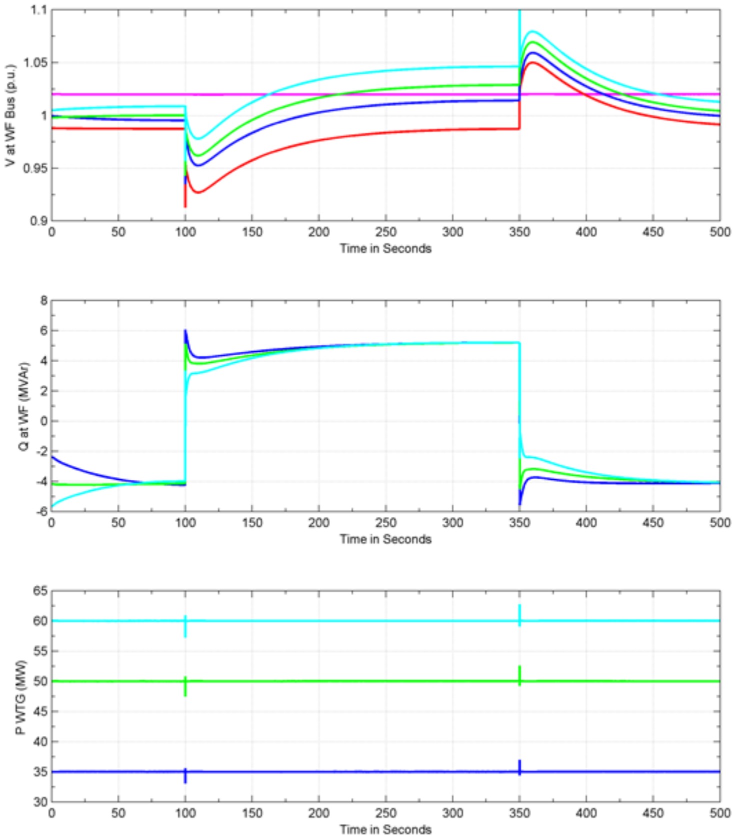

Figure 5 - Response to a Shunt Capacitor Switching with MPC

As is evident in the above figures, with implementation of the MPC scheme, the VArs are balanced between wind plants while regulating the upstream POR voltage.

5.3 Benefits

The MPC function helps wind plants (GE or non-GE equipped) to deliver the greatest benefit to the grid while maximizing the power transfer capability of the transmission system. In a grid without MPC, the voltages in the transmission system drop as a function of power transfer as shown by the purple lines in the figure below. For high power transfers, these voltages may drop below minimums required by the system operator, leading to curtailment of wind power. MPC enables multiple wind plants to regulate the voltage in the transmission system, which can help avoid curtailment by increasing the power transfer capability of the transmission system.

By simultaneously balancing the reactive power load on the basis of each wind plant's reactive capability, each wind plant carrying its share of reactive load. This improves the collective response of the wind farms to grid events that demand reactive power immediately like faults as each plant is able to react and deliver VArs quickly.

Adjusting the voltage reference set-point in a region of the grid may become a manual and tedious process when many wind plants are in the area, and increase the risk of operator mistakes. Implementing MPC allows an operator to adjust a single voltage reference set-point while the MPC controller continually adjusts all of the wind plant voltage references to achieve the desired result, simplifying the routine operation of many wind plants.

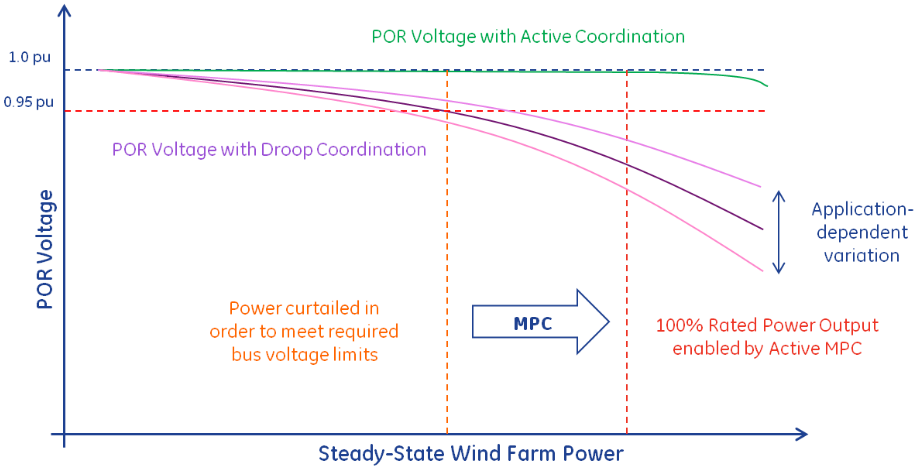

Figure 6 - Power Transfer Capability

5.4 Hierarchical control strategy

Controlling multiple wind plants requires multiple layers of control starting from the turbine controls at the innermost layer to the wind plant level controls at the middle level to the active measurement and communications based controls between multiple wind plants at the topmost layer. For optimal performance of the different layers and to prevent “fighting” between the layers, every subsequent higher control layer is designed to be slower than the one at the immediate lower level. Hence, with this logic, the turbine controls are fastest and the active controls are slowest. Note that the Multi Plant Control (MPC) scheme covers the control layers above turbine control, i.e. at wind plant level and between multiple wind plants. The figure below shows the different control layers.

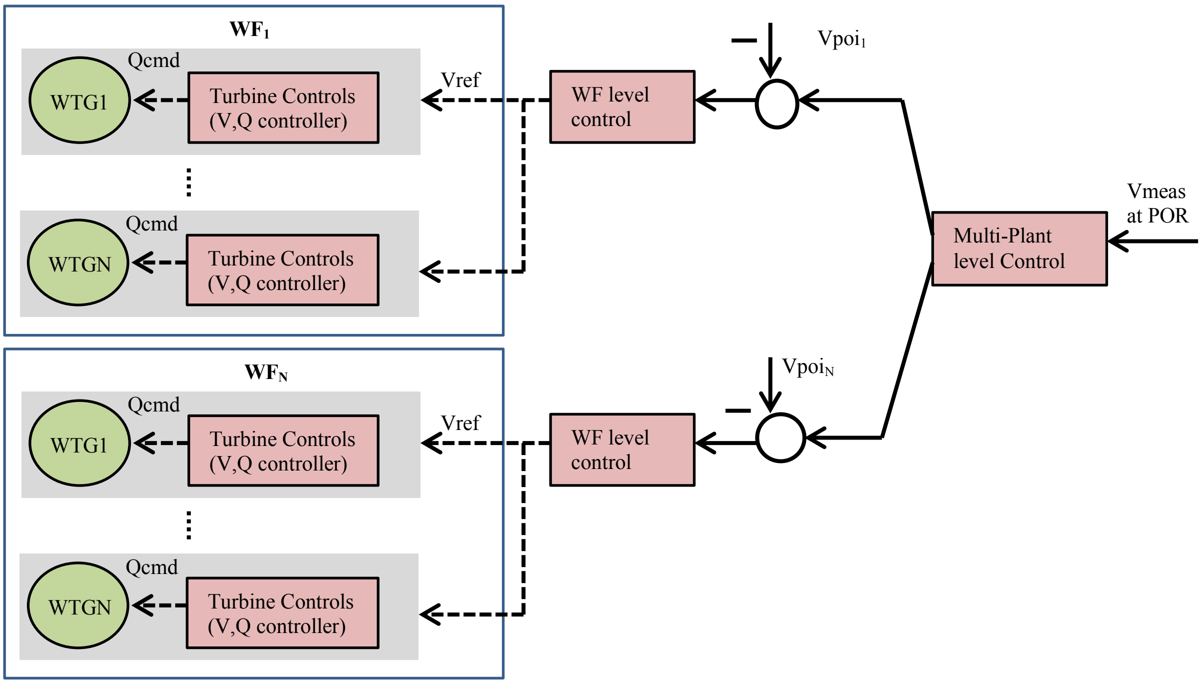

Figure 7 - Hierarchical Control Structure of MPC

6 CONCLUSIONS

As more wind plants are interconnected to the electrical grid, balancing reactive power is likely to become an increasing concern. Some applications with dense groups of wind plants and complex configurations, often cannot achieve the performance required by the grid with passive methods like voltage droop. The operations staff at wind plants is further stretched by the task of adjusting the voltage of many wind plants simultaneously for changing grid and wind conditions, a task that is time-consuming and tedious. MPC offers solutions to these challenges. By coordinating VArs contributions from many wind plants, the reactive capability of each plant is better utilized while reducing losses and improving power transfer capability of the system. MPC also simplifies daily operations by making a large group of wind plants work like one single, large wind plant for voltage adjustments.

7 REFERENCES

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8 BIOGRAPHIES

Matthew Richwine has been with GE since 2009 as a power systems engineer in the wind turbine electrical design team and more recently in GE Energy Consulting, where he focuses on testing and modeling the dynamic performance of thermal and renewable power plants, stability analysis for subsynchronous resonance phenomena, renewable integration studies, and wind turbine plant controller design. He holds a bachelors and masters in electrical and computer engineering from Cornell University.

Sudipta Dutta has been with GE Energy Consulting since August 2013. Her focus is on modeling, control, and integration of renewables with bulk power systems. She has received her PhD from University of Illinois at Urbana-Champaign in 2012 and her dissertation explored graph theory and data mining applications to several power system problems.

Mariana Binda Pereira has been with GE since 2009, and joined GE Energy Consulting in 2012, as part of Latin American group. She works mostly with interconnection studies of wind generation into the bulk power system. She holds a masters degree in Renewable Energies from Oldenburg Universität and a degree in electrical engineering from Universidade Federal do Espírito Santo.