Master's Thesis Proposal

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As the technology behind renewable energy sources becomes more advanced and cost-effective, these sources have become an ever-increasing portion of the generation profile of power systems across the country. While the shift away from non-renewable resources is generally considered to be beneficial, the fact remains that renewable sources present unique challenges associated with their individual generation profiles. Because of the high variability of renewable resources, the stability of the system can degrade. Generators assigned to regulate frequency, keeping it close to the desired 60 Hz, are forced to ramp up and down quickly in order to supplement the rise and fall of the variable resources, causing transient frequency deviations, power swings, major interface transfer variations and other significant issues.

This research aims to measure the impact of renewable resource penetration level on power system stability. Currently, the generally accepted amount of regulation (non-renewable, rapidly-dispatchable reserve, used as a back-up to base generation on a short time scale to avoid stability issues) is 1% of peak load. Because of the high variability associated with renewables, including wind (the focus of this thesis), this value is expected to need an increase of at least a few percentage points. The primary objective is to quantify the amount of regulation necessary to maintain marginal stability as a function of the penetration level of wind generation.

Once this functional relationship is established for the base case, the influence of additional controllable parameters will be considered to determine if the measured regulation level can be decreased while maintaining the same desired stability for a given wind penetration percentage. The increased cost of additional regulation is of fundamental concern; modulating these additional controllable parameters may ease this burden.

Current industry practice typically utilizes a dispatch interval of one hour, in which generational units are re-dispatched in order to reestablish normal reserve margins. Accordingly, the model will assume various dispatch intervals, ranging from the common length of one hour down to five minutes. A shorter dispatch time diminishes load variation from the current set point, and thus will theoretically increase stability without the need for additional regulation.

Next, the thesis will examine the effects of consolidating balancing areas (areas which are required to generate or procure the majority of their load and maintain their frequency over a period of time). An increased number of generators contributing to load-generation matching in a given area will theoretically ease the required ramping of each individual generator and thus increase stability.

Lastly, we will consider the influence of the amount of inertia and “slack” in the system on stability. The inertia of the system should provide a buffer to frequency deviations, because the generators’ masses prevent them from changing speed quickly when correcting an imbalance.

Although the cost of each change described above will not be directly considered, a better understanding of the individual effects of these controllable parameters should prove informative in this regard.

Thus far, current literature has focused on a limited number of wind penetration data points, generally looking at 2 to 3 wind penetration levels with the highest being around 30% wind by energy in a given area [[1](#Pau14)]. The establishment of the true functional relationship between regulation and wind penetration should help to eliminate the need for interpolation between such few points. Additionally, few studies have employed dynamic generation simulations, relying instead on statistical inference. In our analysis of 11 prominent wind integration studies, only a single study ( [[2](#KEM)]) used a dynamic model, and thus only a single study was able to look at second-to-second changes in frequency and generator response (though again at only 2 penetration levels) [[1](#Pau14)]. While statistics may be useful in some specific cases, a dynamic model allows for direct manipulation of system parameters in order to observe the resulting behavioral changes. Accordingly, a rigorous simulation analysis that recognizes multivariable dependencies is well equipped to uncover subtle functional relationships. Furthermore, the dynamic generator model, as opposed to a simple power flow model, recognizes system inertia. While it is generally accepted that inertia provides a buffer, as explained above, there still exists some debate concerning the extent [[3](#Kat09)] [[4](#eta09)]. The quantification of the influence of inertia has not been directly considered and should prove beneficial to support the results of future studies.

In its current state, our model consists of 3 basic layers. Within the innermost layer, we employ a dynamic simulation of the power flow model. The appropriate differential equations (to model the change in generator angle, speed, mechanical power output and change in power due to the governor with respect to time) and the appropriate algebraic equations (to model the power flow along the system) are numerically integrated forward over the current time interval from set initial conditions. The next layer of the model runs an economic dispatch for each of the time intervals, which provides us with the initial conditions for the numerical integration sub-function. Economic dispatch performs a linear optimization under various constraints, calculating the optimal amount of generation to be provided by each generator. Over each time-step of the economic dispatch, the above numerical integration integrates forward, simulating the response until the next dispatch signal. At the outermost (3rd) layer of the model, we check the stability of the system based on the numerical integration over the entire time period using the metrics Control Performance Standard 1 (CPS1) and Control Performance Standard 2 (CPS2), both of which provide a measure of frequency deviations over different time segments. The input system will be a 2 area, 39 bus per area system with 10 non-wind generators and 4 wind generators per area, which is based on a commonly used simplified model of New England.

To review, the proposed experiments will consist of the following:

* Vary wind penetration level as a percentage of wind by energy per area
* Determine the required regulation amount for marginal stability for each wind penetration level
* Decrease dispatch time intervals and measure improvements in stability
* Consolidate balancing areas and measure improvements in stability
* Vary the amount of system inertia and measure changes in stability

The research is expected to form a fully quantified picture of the way in which each of the variables in question influence stability of power systems.

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# Works Cited

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