Scot Backhaus
Los Alamos National Laboratory

The Office of Electricity within the US Department of Energy (DOE) asked Los Alamos National Laboratory to look broadly at the uncertainties within the analytic processes being proposed by NERC to assess the ability of bulk power systems to withstand the stress caused by exposure to large geomagnetic disturbances. DOE did not provide exact direction, rather, Los Alamos was given the freedom to explore any part of the process.

Los Alamos began with the NERC documents that describe both the analytic workflow, the simulation tools used within the workflow, the input data required by the workflow, and the methods used to derive that input data. We agreed with NERC that both the analytic workflow itself and the power system simulation tools that support the workflow were well justified.. We now use one of these mathematical formulations of the power system physics in our own research projects for other federal agencies. However, we did find that input data and the methods used to derive that input data from observational data might require some additional scrutiny.

In our investigation, we found three specific areas that we could study within the available resources. The first was the statistical techniques used to estimate the NERC one-in-one-hundred year benchmark geomagnetic field time series. The second was the statistical treatment of the data used to derive the scaling of that geomagnetic benchmark as function of geomagnetic latitude. The third was the uncertainty of the geologic conductivity data used to convert the geomagnetic fields to geoelectric fields. In some way, each of these is on the list of topics for this panel. Today, I will only comment on the first two of these areas as there are others on this panel who are far more knowledgeable about the third—geologic conductivity models—than me or any of my colleagues at Los Alamos. In the course of our work, we found additional areas that we believe merit additional review, but did not have resources to investigate in the proper depth, for example, the use of spatially-averaged geoelectric fields rather than fields at a point. I will only comment on this last issue to the depth that we have actually put thought into it.

There have been two statistical methods proposed to estimate the NERC one-in-one-hundred year benchmark event. The first is an intuitive method that uses the rate of occurrence of more routinely observed low amplitude geo-electric fields to extrapolate and estimate the rates of higher geo-electric fields—those fields that create power system stresses of concern. In the applications of this method we investigated, no accounting was made for the autocorrelation time of the geo-electric field signal. Our analysis of data from many observing stations shows that a geo-electric signal has an autocorrelation time of approximately two minutes, and this autocorrelation time is relatively independent of the strength of the geo-electric field. Within this time window, samples of the geo-electric field magnitude are not independent, are well described by peak geo-electric field within time window, and this peak field should be counted as a single independent event. NERC analyses using this method have instead counted every sample of the geo-electric field as statistically independent. The effect is to over count statistically dependent geo-electric field observations below the peak values relative to the statistically independent peak values, leading to bias in the shape of the distribution of observed geo-electric fields. This bias magnifies the decay of the geo-electric field observations leading to a systematic underestimation of the rate of occurrence of independent geo-electric field peaks beyond the range of the observed data, that is, in the range of geo-electric fields of importance to the estimation of the benchmark one-in-one-hundred year event. If the effects of autocorrelation time are not accounted for, we believe this this particular statistical method is not adequate for estimating the one-in-one-hundred year benchmark event. Continued use of this method requires, at a minimum, the incorporation autocorrelation time and an accounting for statistical independence of geo-electric field samples.

Extreme value theory has also been used in NERC analyses of the statistics of geo-electric field signals. In this method, only the largest observed geo-electric fields over prefixed time periods or the peak geo-electric fields over a certain threshold are used to estimate the extreme tail of the distribution of geo-electric fields. These observations are generally well separated in time and not affected by the issues of autocorrelation noted earlier. A standard application of extreme value theory should provide an adequate statistical approach.

The scaling of the one-in-one-hundred year benchmark geomagnetic time series with geomagnetic latitude is another key element in the NERC analytic process. This scaling provides some relief from the benchmark event to power systems at more southerly geomagnetic latitude by decreasing the expected geo-electric field at these lower latitudes. However, the geomagnetic disturbance that would create the benchmark event is rather severe and may not behave the same as the smaller, more commonly observed disturbances that the NERC analysis used to establish the geomagnetic latitude scaling.

Power engineers should be very familiar with this general type of argument. Small perturbations to electrical power systems lead to small generator rotor phase and voltage dynamical oscillations. Increasing the strength of these still small perturbations leads to a proportionally larger response of the power system dynamics. However, if the perturbations are increased far enough, the nonlinear response of the power system dynamics, e.g. the electromagnetic restoring torque on generator rotors, results in qualitatively different and potentially detrimental power system behavior.

Our analysis of geomagnetic disturbances shows related behavior. We use geomagnetic time series data from the same observation network and locations used in the NERC analysis. However, we have expanded the data set to include geomagnetic field measurements from many more but less severe disturbances, that is, 122 disturbances compared to the 12 used in the NERC analysis. Here, we use the disturbance storm time (Dst) index as one gross measure of the severity of a geomagnetic disturbance. Instead of averaging the data from all of the disturbances, we bin the data into non-overlapping ranges 100 Dst units wide and average the data within each bin. Averaging is performed using the same methods as in the the NERC analysis.

Binning by Dst enables the identification of trends that may emerge for more severe geomagnetic disturbances with more negative Dst. The least severe disturbances in Dst bins with central values of -150 and -250 show behavior reasonably consistent with the proposed NERC geomagnetic latitude scaling law. These bins contain 94 and 19 disturbances, respectively. The next more severe disturbances in the Dst bin with a central value of -350 show a notable increase in geo-electric field values over the proposed NERC scaling. Normalization by the NERC scaling shows that the largest proportional increase of approximately a factor of two occurs near 52 degrees north geomagnetic latitude with smaller but significant increases over the range between 50 and 55 degrees north geomagnetic latitude. The Dst bin with a central value of -350 contains 7 disturbances—a relatively small number. However, the trend of higher geo-electric fields in the region around 52 degrees north geomagnetic latitude continues for the Dst bins with central values of -450 and -550, which each contain only one disturbance.

Taken together, the nine disturbances with Dst more severe than -300 show a trend of increasing hazard at lower geomagnetic latitudes as compared to the proposed NERC scaling, which is based on the hazard at 60 degrees north geomagnetic latitude. The trend identified in the present analysis indicates that, for severe disturbances, the proposed scaling of geo-electric fields with geomagnetic latitude should be modified to account for the increases at mid latitudes. However, the current NERC analysis should be adopted and further analysis performed with additional observational data and severe disturbance modeling efforts with the intent of refining the geomagnetic latitude scaling law in future revisions.