# Impact of Extreme Weather on Power System Blackouts and Forced Outages: New Challenges

Mladen Kezunovic, *Fellow, IEEE*, Ian Dobson, *Fellow, IEEE*, and Yimai Dong

***Abstract*-- This paper focuses on the impact of extreme weather on power system outages. Extreme weather condition impacts of interest are listed, including both direct and consequential events. Their impact on power system outages are discussed, concerning both blackouts and component failure. Prospects for estimating weather condition impacts on the frequency of blackouts and on equipment and system failures are assessed, and a suggestion of the potential research areas is presented.**

***Index Term*-- extreme weather, power system, blackout, component failure**

## I. Introduction

We are experiencing a world-wide climate change nowadays. As one of the most concerning issues, global average surface temperature has risen by 1.2 degrees Celsius in the last 50 years and is expected to keep rising over the next few decades [1]. Other trends and consequences such as less precipitation in some areas, deforesting, and experience of more destructive weather events are anticipated. If this climate change continues for some decades, the climate in the future will be considerably different from what we have now.

Climate change will have an impact on every walk of human society and economy. Climate change is likely to present opportunities for some sectors and regions, for example, agriculture could expand to regions where it is currently limited by low temperatures. However, climate change also is likely to have numerous negative effects on human development and well-being. There is now an international interest in detecting biotic response to climate change in natural ecological systems, and assessing impacts on economy. The whole society has responded to this issue. "To allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner" has been presented as the goal [2]. Dozens of cities in industrialized countries have adopted GHG emission reduction targets and have taken measures to implement them, mostly in the energy and transport sector.

The interaction of the electric power industry with climate is manifested in two aspects: (i) the contribution of electric power to the production of greenhouse gases (GHG) and other pollutants, and (2) the effect that severe weather has on the power system.

It is estimated that the United States is the source of one-fourth of the world's GHG emissions and that the electric power industry accounts for one-third of the nation's GHG emissions. Within the total GHG emissions, $CO_2$ emissions account for more than 80 percent of the overall U.S. contribution and 38 percent of this amount comes from the electric power sector [1].

In the meantime, extreme weather events such as heat waves are experienced more frequently with longer durations in U.S., affecting transmission line conductor sags and other equipment that needs to be cooled off (transformers, rotating machinery).

The approaches that can aid in the mitigation of and adaptation to climate change trends have to be embraced by the utility industry. The following issues are important in studying the approaches: (i) power infrastructure capability to respond to climate change and extreme weather events; (ii) relative impact of climate change on system operating strategies (e.g., system dispatch), system configurations (e.g., network islanding and microgrids), and expansion plans; (iii) system effects of an expanded use of renewable and alternative energy technologies; and (iv) impacts of market rules and policy mandates on the operations of the power system and sustainability and, subsequently, on the national economy.

This paper focuses on the effect of extreme weather on power system. Electric power systems are usually designed to operate during periods of relatively stable weather and loading patterns. These design assumptions may be strained by extreme weather due to climate change. The extreme weather of interest includes directly destructive events such as high winds or ice storms as well as extremes of heat and cold, which affect both individual equipment failure and system operations. The effects of extreme weather will combine with the effects of other changes such as population migration and changes in water availability.

Since power systems need to be designed and operated with respect to extremes of weather and peak loading, it is necessary to quantify likely changes in the statistics of these extremes due to changes in climate. In this paper, we evaluate the prospects for estimating the frequency and impact blackouts and of equipment and system failures. A readable account of the climate science supporting the extreme weather trends and predictions is in reference [1].

This paper is based on material from PSerc report [3].

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## II. Extreme Weather

This section discusses the predicted extreme weather trends that will directly impact electric power systems in the United States and Canada. Over the next 20 years, the average global surface temperature is expected to rise about 0.2 degree Celsius per decade. Over the next 100 years, the average global surface temperature is expected to rise between 0.2 to 0.4 degree Celsius per decade, depending on the human response to climate change [4]. We expect this slow average temperature increase to have a slight direct impact on power systems. The key issue is the increase in the variability of temperature, precipitation, and other weather extremes.

The IPCC 2007 report (reference [4]) identifies the following trends and expects them to continue for the next 100 years. The likelihood of these future trends exceeds 90 percent, according to expert judgment.

- Warmer and more frequent hot days and nights, and more frequent heat waves;
- Increased proportion or frequency of heavy precipitation;
- Warmer and fewer cold days and nights.

Also predicted with likelihood greater than 66 percent are changes in hurricane intensity; that is, hurricanes are likely to have stronger winds and more precipitation.

It is clear that these changes in weather extremes can impact the power system infrastructure, but assessing the nature of this impact requires quantifying the rate of change of the weather extremes and comparing this to the rate of change of the power system infrastructure. The power system infrastructure changes on a time scale of decades. (The typical lifetime of a power plant is 30 to 50 years and a typical lifetime of a transformer is decades; a new transmission line can take about a decade to plan.) If extreme weather changes occur on a timescale slower than decades, then the power system can adapt to the extreme weather changes by having specially designed expansion and equipment according to the current weather extremes. On the other hand, if the extreme weather changes significantly on a timescale of decades, then either the power system will require uprated designs and more upgrades and maintenance, or the power system reliability will decrease.

How to extract quantitative estimates of the rate of change of weather extremes from the climate change literature remains a challenge. We are interested in the changes per decade over the next hundred years. Many studies of the impact of climate change assume either a given average temperature increase or a doubling of the atmospheric carbon dioxide concentration.

The time over which a given average temperature increase or doubling of the atmospheric carbon dioxide concentration occurs depends on the human response to climate change. This is accounted for by considering several different scenarios of human response. The time for a one degree Celsius average temperature increase ranges from about 25 to 50 years (using best estimates in Table SPM-2 in reference [4]). The estimated date for the atmospheric carbon dioxide concentration reaching double its pre-industrial level of 280 ppm ranges from approximately 2050 to 2100 [1]. Fig. 2 shows an obvious increase in emission of GHGs (Green-house gases) from 1970 to 2004.

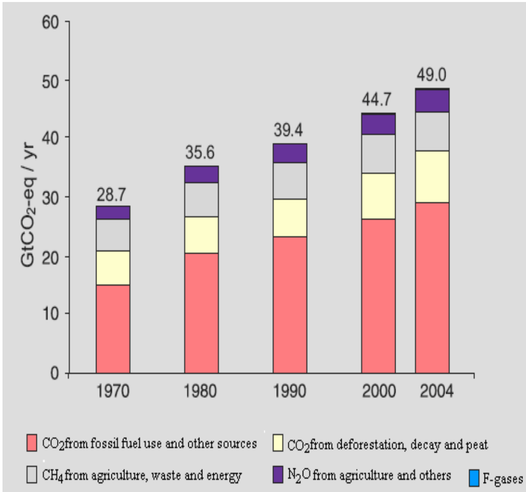


Fig. 1. Global annual emission of GHGs from 1970 to 2004[1]

There is considerable inertia in climate change in that the global average temperature will continue to rise even if carbon emissions are sharply reduced.

We consider an example of extracting data from a climate study. Interpolation of climate model data in page 158, reference [1] suggests that a four degree Celsius warming in the Sacramento River basin in California would reduce the average September runoff by about 50 percent and increase the average January runoff by 40 percent. In the meantime, an increase in global average surface temperature is also observed (Fig. 2). If the regional temperature increase follows the global average temperature increase, the four degree Celsius increase would occur in 100 to 200 years. This is proportional to a 2.5 to 5 percent reduction in September runoff per decade and a 2 to 4 percent increase in January runoff per decade (Fig. 4). This calculation gives a rough value of the change per decade to gain an appreciation of the magnitude of the rate of impact on hydro resources. However, the regional temperature change will differ from the global average temperature change, and estimates for planning and decision-making should use the regional predictions of temperature change. Regional models of climate change exist and are improving, but the global average temperature models are more accurate than regional models. The IPCC report and reference [2] need to be updated to reflect the most recent literature.

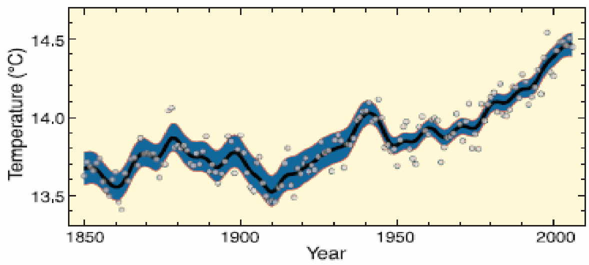


Fig. 2. Change in global average surface temperature from 1850 to 2000[2]

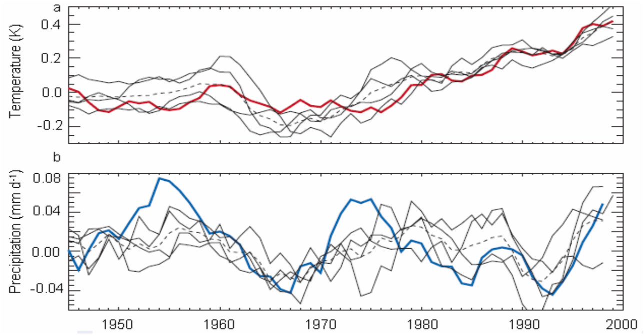


Fig. 3. Impact of global average temperature on land precipitation estimated using different models[7]

## III. Extreme Loading of Power System

Growth in the demand and change in load patterns may create major bottlenecks in the delivery of electric energy. This would cause power system stress as operational conditions approach thermal and mechanical ratings of power system elements such as transmission lines, transformers, circuit breakers, etc. These conditions may contribute to deterioration of dielectric materials, operating mechanisms, supporting structures, and cooling/insulating liquids used in power apparatus. As a result, overall wear and tear impacts may be greater, leading to increased vulnerability to faults and/or breakdowns.

The effects from climate change will be exacerbated by other unusual changes not caused by climate change but whose effects combine with the effects of climate change. For example, population migration in the U.S. will affect loading patterns significantly, particularly in the West and South. When combined with the change in temperature and increase in inclement weather conditions in the same areas, two issues need to be considered when assessing impacts on the power systems:

A significant increase in population in the areas most affected by climate change puts additional stress on the system due to an increase in demand. This increase is the result of not only the existing population using more (peak) electricity but also the increasing peak load from population migration patterns.

A significant increase in population in areas with high risk for weather-related disasters brings a new dimension to planning for emergencies and related strategies for electricity service restoration. Climate change will affect more citizens if the electricity service disruption is caused by this change.

## IV. Overall Impacts on Power Systems

The warmer and more frequent hot days will increase the peak load in summer-peaking regions at the same time as stressing power system components. Thermal limits on components are more restrictive on hot days. If components are not derated to allow for this, they may fail more frequently, age faster, and require more maintenance and earlier replacement. Control equipment may require recalibrating to derate the equipment. Problems have occurred with transformers designed to cool off at night being unable to cool down sufficiently during warm nights and therefore begin the next day with higher starting temperatures.

If more extreme wind gusts occur, they would cause tower and conductor damage and more faults due to galloping and trees falling. If an increase in hurricane intensity occurs, it would be necessary to uprate designs and to consider shifting more resources to emergency planning and restoration. This is particularly true if population migration brings more citizens to areas that are prone to power outages due to extreme weather conditions. The more population movement to the given area, the more careful planning for emergencies and recovery is needed. Fig. 4 shows damage rates related to wind velocity. Similar study should be done to the power system specifically.

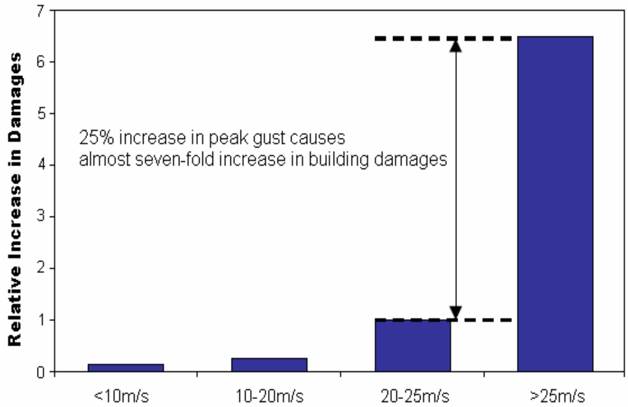


Fig. 4. Damages caused by gust with different wind velocities[7]

River water runoff is very sensitive to changes in climate, and small changes in temperature and the amount of precipitation can have a significant influence. Higher temperatures increase water evaporation and decrease runoff (page 158-159, reference [1]). A regional temperature rise of a few degrees can increase winter runoff and decrease summer runoff. Arid regions may experience higher variability in precipitation. The increase in heavy precipitation may stress the systems to control river flow. There may be an increase in large floods with the consequent risk of damage to the electricity infrastructure [5]-[6]. All these effects would affect hydro energy resources and scheduling.

It is possible that drought (affected by climate change) combined with exhaustion of aquifers (unrelated to climate change but important in water resources) could lead to population shifts that change load patterns.

## V. Effect of Catastrophic Wildfires

Climate change is thought to contribute to catastrophic wildfires in the western United States, Alaska, and Canada as a result of longer, warmer growing seasons. Once trees have died back, the landscape is prone to intense crown fires rather than surface fires that are more easily suppressed. Drought that enhances insect populations and subsequent wildfires directly dries other fuels, leaving forests of healthy, living trees that are more vulnerable to crown fires. In addition, years of fire suppression have greatly increased understory fuels in the dry, lower-elevation forests of the western U.S., turning normal surface fires into crown fires [7]. Increased fire activity could have significant repercussions for the transmission system infrastructure.

## VI. Estimating Effect on Blackouts

Estimating overall blackout risk is an ongoing and emerging topic, and it may become feasible to use these emerging methods to estimate the effects of climate change on overall reliability [8]. The likelihood of blackouts of various sizes is thought to be mainly affected by the size of the initial disturbance to the power system (such as caused by extreme weather) and the extent to which the disturbance propagates via cascading failure. The size of the initial disturbance when the weather is more extreme is probabilistic, and it would be necessary to quantify the statistics of the extreme weather parameter, such as wind speed, and relate it to the initial damage to the power system. Some extreme weather events such as a heat wave would also tend to load the power system so as to increase the propagation of cascading failure.

## VII. Estimating Effect on Component Design and Maintenance

The existing power system infrastructure in the United States is valued at $800 billion. Replacing such an infrastructure with new components having ratings required to sustain climate and load changes is unrealistic. Hence, an incremental strategy for making improvements is more likely to prevail. Three approaches may have some promising impact:

- Implementing condition-based maintenance strategy aimed at estimating the remaining life based on online measurements, prevailing system operating conditions, and history of thermal/mechanical stresses.
- Retrofitting and reinforcing existing infrastructures with more robust construction and control solutions that can better respond to extreme weather and load patterns.
- Deploying automated restoration procedures that can bring the system back faster after the extreme weather causes damage and service interruptions.

The above-mentioned strategies may lead to new requirements for designing power system information infrastructure as well as power apparatus. It may also lead to the development of new techniques for estimating the combined impacts of climate and load extremes that are more complex than the ones used to date.

## VIII. Possible Research Areas

Concern over global climate change and its effects on human society, sustainability and national economies is increasing. As part of the ongoing national and international discussions of climate change, it is important to develop potential research areas that address the interactions between the electric power industry and global climate change debate. Lists of possible research areas are outlined:

- Combine climate predictions of extreme weather with blackout risk assessment techniques under development by PSERC to estimate the impact of climate change on blackout risk.
- Explore power system monitoring and control techniques more amenable to self-healing properties, particularly under harsh weather conditions and increased load demand.
- Review climate change prediction studies for regions of North America, and use these to estimate the rate of change of power system design parameters such as temperature, wind, and precipitation extremes so that component design parameters can be uprated and loading forecasts changed as necessary.
- Design a better service restoration methodology in case of natural disaster such as hurricanes, high wind and rain, or snow storms.
- Analyze the likelihood and impact of increased wildfires on the western power grid and transmission system equipment.

## IX. Conclusion

Climate change brings new and unexpected challenges to power system design and operation. This paper reviews the trends in the future global climate and provides a discussion on the impact on power system blackouts and equipment failures. New technical issues facing the electric power industry are listed. Possible research areas are presented, with an emphasis on including weather factors in estimation and analysis of power system blackouts and equipment failures.

## X. Acknowledgement

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## XII. Biographies

**Mladen Kezunovic** (S'77, M'80, SM'85, F'99) received his Dipl. Ing. Degree from the University of Sarajevo, the M.S. and Ph.D. degrees from the University of Kansas, all in electrical engineering, in 1974, 1977 and 1980, respectively.

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His main research interests are digital simulators and simulation methods for equipment evaluation and testing as well as application of intelligent methods to control, protection and power quality monitoring. Dr. Kezunovic is a registered professional engineer in Texas, member of CIGRE, and a Fellow of the IEEE.

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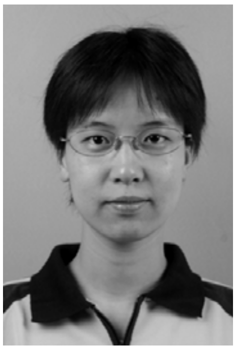
He worked as a systems analyst for the British firm EASAMS Ltd. from 1978 to 1983. In 1989 he joined the University of Wisconsin-Madison USA, where he is now professor in electrical and computer engineering.

His current interests are cascading failure risk and complex systems approaches to blackouts.



**Yimai Dong** (S'07) received her B.S. and M.S. degrees from North China Electric Power University, Beijing, China, in 2005, 2007 respectively, all in electric engineering. She has been with Texas A&M University pursuing her Ph.D. degree since August 2007.

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