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How is Climate Change Likely to Affect Queensland Electricity Infrastructure into the Future?

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***Abstract*—In order to plan efficiently and cost effectively, utilities must take a long-term outlook on their transmission and distribution utility assets. Climate is important to consider, especially when a significant proportion of Queensland is affected by extreme weather events including cyclones, flooding and heat. However, why the climate is changing is due to human-related activities. Therefore, a study was performed to identify the changes which could be expected to occur in Queensland, and how this may affect utility operations. Literature provided by various government bodies and utilities was reviewed and analysed. The study highlighted several instances where direct damage to infrastructure will increase due to tropical cyclones and flooding, requiring adjustments to utility asset management plans. It is likely that this will result in more frequent electricity supply interruptions. Additionally, increasing summer temperatures and heatwaves due to climate change will increase peak load demand. Additional generating capacity may be required to meet this demand.**

***Index Terms*—Global warming, Power grids, Power system planning, Power system reliability, Tropical cyclones.**

I. INTRODUCTION

In a recent study, the United States National Climate Assessment and Development Advisory Committee (NCADAC) reported that extreme weather events such as intense storms, hurricanes, flooding, droughts, and bushfires are increasing in frequency in their country [1]. This report outlined how extreme weather events are affecting transmission and distribution systems, causing damage to infrastructure and disruptions to energy supply. For example, rising sea levels, heavier rainfall and more intense coastal storms are projected to cause more frequent inundation and flooding. The study concluded that climate change is negatively affecting power systems in the United States, and that the impacts are projected to become worse.

The United States report provided the motivation to carry out a similar study on Queensland, Australia. For instance, the Intergovernmental Panel on Climate Change (IPCC) has stated that increasingly intense rainfall in Queensland is producing more frequent flooding [2]. More than 300,000 customers lost power as a result of the 2011 floods in south east Queensland, and the repairs cost the local electricity distributor, Energex, AU$40 million [3]. There is strong evidence that floods such as these, as well as other extreme weather events, may become more frequent in the future.

It is therefore important to study how energy supply systems are being affected by climate change. Network businesses and policy makers can then implement sensible mitigation and adaptation techniques to ease future impacts. Despite a thorough review being performed, very little literature was found which comprehensively summarised the impacts of climate change on Queensland's energy supply. This study then focused on the following two aspects. Firstly, how a changing Queensland climate was likely to affect the electrical utilities. Secondly, to make recommendations to suitable mitigation strategies for governments and distribution and transmission network service providers (DNSPs and TNSPs) in Queensland.

II. REPORTED CHANGES TO QUEENSLAND CLIMATE

The majority of the climate data and projections cited in this study were sourced from the IPCC, CSIRO and Bureau of Meteorology. All scientific work undertaken by these organisations is subject to extensive expert peer review processes, which affirm the credibility of the information used. The 2013 IPCC Fifth Annual Assessment report [2] represents one of the most authoritative and comprehensive scientific assessments of climate change to date. The key findings and projections relevant to Queensland include:

1. Projected 60% increase in intensity of the most severe storms by 2030 and 140% by 2070 [4];
2. Projected increase in tropical cyclone intensity (greater proportion of category 3-5), but overall decrease in the frequency of cyclones. Occurrence of cyclones 100km further south from 2051-2090 relative to 1971-2000 [2];
3. Increased frequency and intensity of flooding due to extreme rainfall [2]; and
4. Increased frequency and intensity of heatwaves [2], [5]. Hot days and nights more frequent and cold days and cold nights less frequent during the 21st century [2]. Number of days above 35°C to increase [5].

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The first three points relate to the resilience of electrical infrastructure. A utility could either incur extra costs from network reinforcement, or its reliability metrics may fall. For the fourth point, hotter days relate to larger load demand from air conditioning. A problem with peak demand is that a utility must design its network to meet this peak, which is inherently inefficient because the capacity will only be required a few times a year.

III. Analysis of Climate and Effect on Infrastructure and Operations

A. Tropical cyclones and damage

Wind-carried debris and high velocity winds during tropical cyclones directly damages overhead lines, poles and other essential equipment. This can result in a widespread loss of electricity supply with potentially lengthy repair time frames. Although there appears to be a decreasing trend in cyclone activity (Fig. 1, data sourced from [6]), the variance in data year-to-year might be too large to comment on significance. However, recent literature has indicated that since the 1970s the tropics have expanded south at a rate of 0.5 – 1 ° per decade (1 ° is 111 km) [7]. Consequently, while the utilities have programmes to mitigate the effects of cyclones in north Queensland, these may need to be repeated further south.

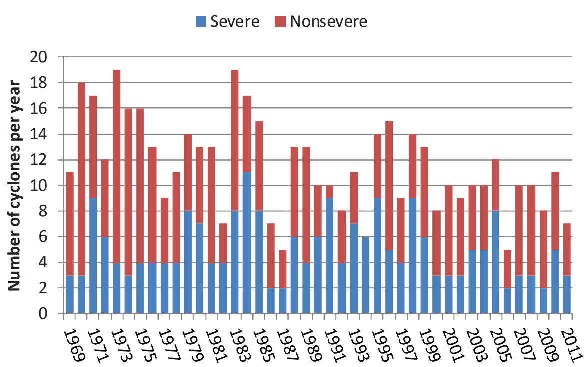

Fig. 1. Number of severe and nonsevere cyclones per year in the Australian region, data sourced from [6]

In 2006 category five tropical cyclone Larry had a significant impact on infrastructure in northern Queensland. Seven of TNSP Powerlink's 132kV overhead transmission lines went out of service, mostly due to fallen trees and flying debris [8]. High force winds collapsed five steel transmission towers and caused severe damage to another two. This resulted in electricity supply interruptions for more than 140,000 customers [8]. Most of the transmission circuits, which had tripped out, were returned to service within two days, except the two lines to Innisfail (where a tower had collapsed). Within five days the collapsed tower had been replaced by flying in one with a helicopter.

The Ergon Energy distribution network had also been badly damaged by cyclone Larry, taking four weeks to restore power to all properties [9]. Ergon Energy spent AU$42.5 million after the cyclone rebuilding the network [9].

Queensland DNSP reports and local newspaper articles were analysed to determine the typical number of customers affected by outages caused by tropical cyclones of different magnitudes. The results are shown in Fig. 2. Over the past 10 years whenever a category 5 cyclone has crossed Queensland, and has reached a populated area, there have been a significant number of customers affected, ranging from 50,000 – 220,000 customers. Cyclones of category 3 or above usually seriously damage the distribution network, which is not designed to withstand wind speeds in excess of 175 km/h. The transmission grid is however designed to withstand wind speeds of up to 260 km/h. However, vegetation foliage is usually blown across the line causing short-term outages.

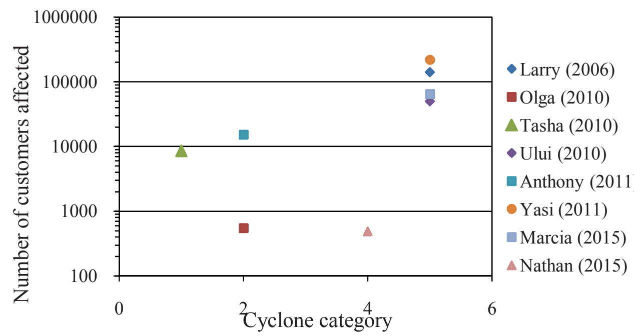

Fig. 2. Effect of cyclone category on number of customers affected

To reduce the impacts of cyclones, Powerlink has completely rebuilt the 55 year old 132 kV transmission line running along the far north Queensland coast (from Townsville to Cairns) with a dual voltage 275/132 kV line, built to the latest design standards. Some of the towers of the original line had collapsed during cyclones Winifred, Larry and Yasi. The new line, which had been partially built between Cairns and Tully, withstood cyclone Yasi with only minimal damage. This new line, along with substations, cost approximately AU$500 million, and has significantly improved the capacity and resilience of the supply in tropical Queensland. Powerlink has also spent a further AU$300 million strengthening the transmission grid around Townsville, and from Townsville to Bowen and Mackay.

Ergon Energy has undertaken various projects in the past to improve cyclone resilience along the north Queensland coast, in areas most affected by cyclones (see 3a). In 2001 Ergon Energy established a Cyclone Area Reliability Enhancement (CARE) program [10] to improve network resilience specifically in populated coastal areas north of Mackay (3b).

Ergon Energy's CARE program includes the following four initiatives [10]:

1. Placing high voltage (HV) power lines underground in key cyclone-prone sections of the network;
2. Installing low voltage (LV) spreaders (horizontal bars) between open wire lines to stop conductor clash – common during high winds that accompany tropical cyclones and severe storms. Newly installed LV services use insulated bundled conductors negating the need for this;

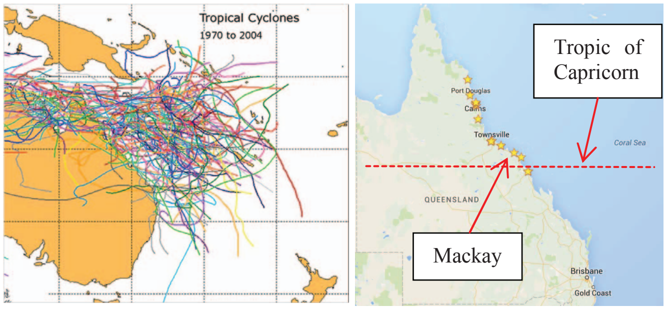

Fig. 3. (a) Historical tropical cyclone tracks 1970 – 2004 [11] and (b) Locations of Ergon Energy CARE program cyclone resilience projects since 2001 (image generated using Google Maps [12])

3. Retrofitting LV fuses on distribution transformers in target areas (as opposed to just the HV side of the transformer as is traditionally the case). This reduces hazards and the risk of infrastructure damage if the LV conductor comes in contact with the ground; and
4. Encouraging customers to underground service wires to their premises.

To date over AU$68 million has been invested in north Queensland on CARE projects, with another AU$18 million committed in active projects [13]. If cyclones track further south, as expected because the tropics are expanding, this highlights the potential costs involved for the network south of Mackay to match the efforts already undertaken in north Queensland. Network reliability may be compromised if energy network businesses do not invest in infrastructure resilience initiatives similar to that of the CARE program.

B. Flooding and damage

While north Queensland is susceptible to cyclones, the south has experienced extreme flooding (which according to the IPCC may become more frequent). Over the 2010-2011 summer months serious flooding occurred in the Brisbane river basin. A total of 475 of DNSP Energex's distribution substations were affected [14]. A summary of the equipment replaced by Energex due to flood damage is given in Table I [15].

TABLE I. EQUIPMENT REPLACED BY ENERGEX DURING 2011 FLOODS [15]

Equipment	Number replaced
Distribution transformers	101
Switch fuse gear	55
Substation relays	55
Watt hour electricity meters	3645
Poles	95
Overhead cable	98 km

In Fig. 4 Energex's 2010-2015 operating expenditure (OPEX) for emergency response/storms was plotted over time to gauge the economic impact of extreme weather events such as the 2011 floods. Their expenditure in 2010/11 and 2012/13 was significantly higher when compared to the other years. This was partially attributed to the emergency response costs of dealing with the 2011 floods and ex-Tropical Cyclone Oswald in 2012. The 2010/11 expenditure was AU$37.4 million, roughly four times higher than the average over other years in the period (excluding 2012/13 due to ex-Tropical Cyclone Oswald). If floods become more frequent and intense due to climate change then operating expenditure 'peaks' such as these may be expected to also become more common and increase in magnitude.

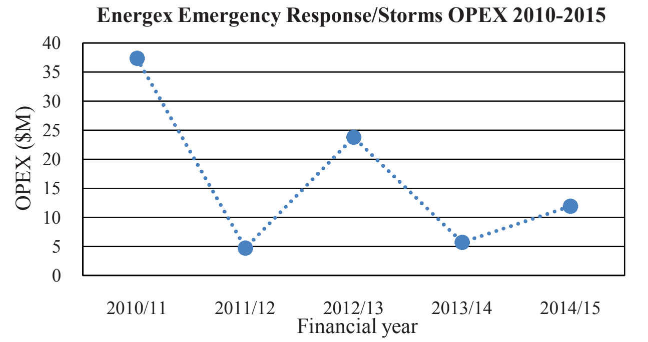

Fig. 4. Energex emergency response/storms OPEX 2010 – 2015 (data obtained from [16])

C. Heatwaves and effect on load demand

The mean temperature of Queensland's east coast has already increased by 1-1.5 °C since 1910 and is projected to rise further due to climate change [2]. According to Ergon Energy, air-conditioners have the largest impact on peak demand on their network during the summer [17].

A study by the CSIRO and the Queensland Department of Natural Resources and Mines [18] explored the relationship between temperature and peak demand across Australia. The results for Brisbane (Fig. 5 below) demonstrate a reasonably linear increase in peak demand of approximately 2% per 1 °C temperature increase. The effect of a heatwave, in 2011, on demand across the whole NEM [19] can be seen in Fig. 6.

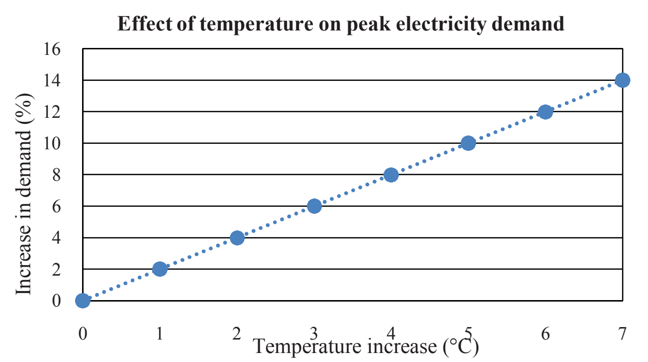

Fig. 5. Change in peak electricity demand (%) in Brisbane due to rising temperatures (reproduced from [18])

Both Energex and Ergon Energy have implemented demand management programmes to encourage customers to reduce their consumption during peak hours [17], [20]. However, an increase in frequency of heatwaves may require either further measures, or retaining a sufficiently high margin in network capacity to supply these peaks.

Installing residential PV is beneficial in this case because the generated electricity partially offsets the midday peak load.

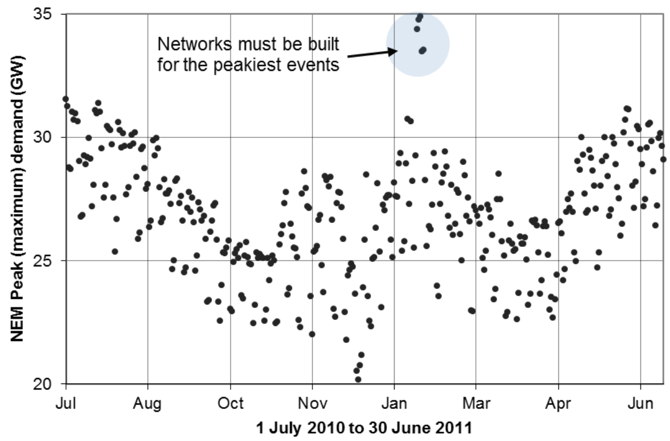

Fig. 6. NEM peak demand from 2010-2011 [19]

D. *Heatwaves and effect on infrastructure*

Increasing mean ambient temperatures and longer, more frequent, heatwaves will directly affect asset management in several ways.

1) Transformers

The expected life of transformer cellulosic insulation is halved for every 6 °C increase in temperature [21]. The maximum temperature reached by the transformer insulation is dependent on the ambient temperature, the temperature rise within the unit (due to the load), and time. More frequent heat waves will affect transformer temperature in two ways.

Firstly, an increase in the number of very hot days will increase the ambient temperature that the transformer is operating in. CSIRO is projecting the number of very hot days (those above 35°C) per year in Brisbane to increase by as much as 20 times by 2100 under a high-emissions scenario [4]. In coastal North Queensland, the present average of 3.8 days above 35°C per year is projected to increase to 6.6 days by 2030 under a moderate emissions scenario [5].

Secondly, increased air conditioning demand due to heatwaves and extreme temperatures will increase peak currents. This will place higher thermal stress on transformers (and other assets), ageing the insulation faster. The risk of failure for other parts of the transformer (such as gasket materials and parts sustaining the axial pressure of the winding block) is also increased with higher temperatures [21]. Mitigation strategies include installing residential PV, which offsets the load requirement during the day, and derating the transformer.

2) Overhead lines

Increasing mean and extreme peak temperatures due to climate change will cause thermal expansion in overhead power lines [22]. The utilities usually use a dynamic rating model to determine the allowable line rating, based on the ambient temperature and wind speed, and some further derating could occur.

3) Underground cables

For underground cables, the thermal resistance of the insulation and external environment (soil, backfill, etc.) has the largest effect on cable current ratings [23]. For the majority of underground cables, the thermal resistance of the external environment accounts for more than 70% of the temperature rise within the conductor [23]. Since the thermal conductivity of soil is not constant, and varies depending on the moisture content (among other factors), calculating ratings for these cables can be a complex process.

Increasing temperatures due to climate change may increase soil thermal resistance if soils become dry as a result (since air temperature correlates well with soil temperature [24]). This reduces the ability of the soil to dissipate heat from the cables, reducing the maximum load the cable can carry before overheating. This is exacerbated by increased peak loads from air conditioning during summer months due to climate change.

In 1998 a blackout in the Auckland CBD lasted five weeks after a series of four cable failures [25]. An investigation revealed that one of the main reasons for the initial cable failure was incorrect soil thermal resistance calculations brought about by the unusually dry and hot weather coupled with prolonged high load from air conditioner use [25]. It may be necessary for utilities to re-evaluate their calculations of cable ratings due to climate change, since assumptions about soil temperature and thermal resistance were mostly done over 50 years ago [22]. Additionally, dry conditions can lead to increased ground movement which can damage cables and joints [22].

4) Steel and concrete

Changes in temperature, humidity and the concentration of atmospheric carbon dioxide (CO_2) levels have the potential to affect the many steel and concrete structures used in electricity networks.

A study performed on steel structures in coastal areas near Brisbane projected changes in corrosion rates by combining global climate and corrosion models [26]. By 2100, a 14% increase in corrosion was expected for both zinc and steel, caused by climate change [26]. For exposed structures, increases in local rainfall may raise this figure by a further 10% [26]. This could affect a large percentage of transmission and distribution assets such as steel lattice transmission towers and steel poles.

An increasing level of CO_2 is also expected to reduce the expected life of concrete structures [2]. Scientists from the University of Newcastle and the CSIRO predicted in 2012 that the risks of damage, from corrosion accelerated by climate change, may increase by 16% by 2100 [27]. They recommended an additional 10-5mm building coating to mitigate this effect. This recommendation may need to be considered by the Queensland utilities.

IV. RECOMMENDATIONS

The impacts of climate change and the existing strategies identified in the previous sections helped scope the following list of recommendations to utilities. The aim of this list is to outline the general opportunities that exist for climate change mitigation and adaptation which utilities may implement. It is recognised that effective strategies will differ regionally and for different network topologies and so the recommendations in this list are intentionally broad. The recommendations include:

- Update asset management, design and construction standards to reflect changes in climate likely to cause physical impacts on networks: floods, storms, higher temperatures. Assets at risk should be identified and designed to operate safely and efficiently under these changed conditions – e.g. raising ground equipment that is vulnerable to water, building new structures to withstand higher wind speeds in cyclone-prone regions;
- Place distribution networks underground where feasible (effective against physical impacts but expensive option since cost ratio increases with operating voltage – unlikely to be practical over long distances [28]);
- Establish a developed emergency response plan for extreme weather events to minimise the extent of outages. This should take climate change projections into account;
- Reduce greenhouse gas emissions to lower the human contribution to climate change – e.g. move towards more renewable energy technologies, reduce line losses, increase efficiencies, manage sulphur hexafluoride leakages (a greenhouse gas used in electrical equipment [28]), reduce emissions from general business operations; and
- Consider rising temperatures in future load forecasting and expansion of infrastructure.

V. CONCLUSIONS

The projected increasing intensity of tropical cyclones and flooding is likely to result in increased damage to assets and more frequent supply interruptions. Affected assets include ground and pad mounted switchgear and transformers, pole foundations, overhead lines, substation buildings and structures, underground cables and joints. Utilities should update their asset management plans to account for this. Electrical assets at risk should be identified and designed to operate safely and efficiently under these changed conditions. Measures could include raising ground equipment that is vulnerable to water and building new structures to withstand higher wind speeds in cyclone-prone regions. Where feasible, building underground networks (and/or undergrounding existing infrastructure) would reduce the risk of damage.

Increasing temperatures and summer heatwaves will affect ageing rates of many assets such as transformers and steel and concrete structures. The current carrying capacity of underground cables will also be affected due to changes in the moisture content of the soil. If utility load calculations are not updated to account for this, there may be an increase in the number of unexpected outages.

In order to ensure a reliable power supply for the future the Queensland utilities need to consider how predicted changes to climate could affect their network and plan for this eventuality.

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