RNC/QuakeCoRE Distributed Infrastructure

14th December **2020**

Power System Resilience Enhancing Techniques for Pre, During and Post High Impact Low Probability (HILP) Weather Events

Draft Research Slides: Project still under development and being presented here for RNC-2/QuakeCORE researcher discussion & ideation

Lakshita Lakshita and Nirmal Nair

National Science Challenges

RESILIENCE TO NATURE'S CHALLENGES

Kia manawaroa – Ngā Ākina o Te Ao Tūroa

RNC Phase 1: Power System Group at University of Auckland

Infrastructure and Built-Environment Solutions

1. Networks and Components
2. Network Interdependencies
3. Performance Measures and Impacts
4. Electricity Distribution Resilience Framework

Electricity Distribution Resilience Framework

This project, funded from the Challenge's contestable funding process in 2017, is developing a novel electricity resilience framework, along with a realistic micro-grid restoration solution enabled through communication lifelines, following a significant Alpine Fault earthquake.

Network: West Coast
Hazard: Earthquake

- Power System Resilience
  - Asset Resilience
    - 2010-2011 Canterbury Earthquake Sequence Impact on 11kV Underground Cables
      - UG Cable Network
        - Ebad Ur-Rehman
  - System Resilience
    - NZ Electricity Distribution Network Resilience Assessment and Restoration Models following Major Natural Disturbance
      - Electricity
        - Duncan Maina
        - Samad Shirzadi
        - Safa Al-Sachit
      - Communication
        - Farrukh Latif

RNC Phase 2: Power System Group at University of Auckland

Built Environment Theme

1. Horizontal Infrastructure
2. Vertical Infrastructure
3. Integrated Scenario

Weather and Wildfire

1. Hazard modelling
2. Extreme scenarios
3. Hazard mitigation

Horizontal Infrastructure

- *Models for infrastructure component performance across a range of natural hazards.*
- *Expanded geographic coverage and capabilities of infrastructure network models.*
- *High resolution regional and urban interdependency models.*
- *Decision making and rating tools for infrastructure.*

Assessment of Electricity System Impacts and Management Strategies Pre- and Post- HIW Events: Northland-Auckland-Waikato Weather Scenario

Outline

Background

- Electric Power System Introduction
- Challenges with Operation and planning of Power System

Introduction to Electric Power System Resilience

- High impact low probability (HILP)
- Understanding of Resilience & Enhancing Techniques

Proposed Framework

- Assessment of Electricity System Impacts and Management Strategies Pre- and Post- HIW events: Northland-Auckland-Waikato Weather Scenarios

Research Stages

Literature Review → Research Idea & Plan → Methodologies and Approaches → Collecting Data → Assess the Northland-Auckland-Waikato Network → Management Strategies Pre- and Post- HIW Events

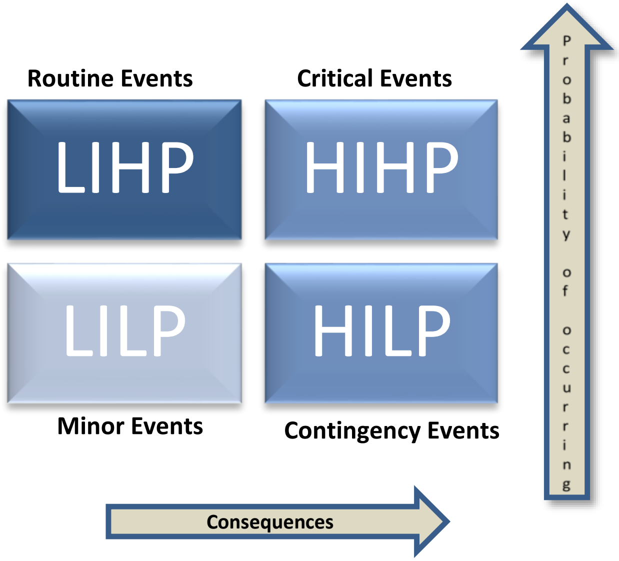
Developed framework for this Research: Literature Review; Research Idea & Plan; Methodologies and Approaches

Currently at this stage: Collecting Data

Next Steps: Assess the Northland-Auckland-Waikato Network; Management Strategies Pre- and Post- HIW Events

Abbreviations

High Impact Weather-HIW (Extreme Weather Events)
High Impact Low Probability – HILP
Low Impact High Probability – LIHP
Low Impact Low Probability– LILP
High Impact High Probability – HIHP
Mean time to Failure – MTTF
Mean time to Repair – MTTR
Distributed Energy Resources – DERs
Renewable Energy – RE
Power System – PS



Electric Power System Introduction

Power System consist of:

- ➢ Generation System
- ➢ Transmission
- ➢ Distribution
- ➢ Load Demand

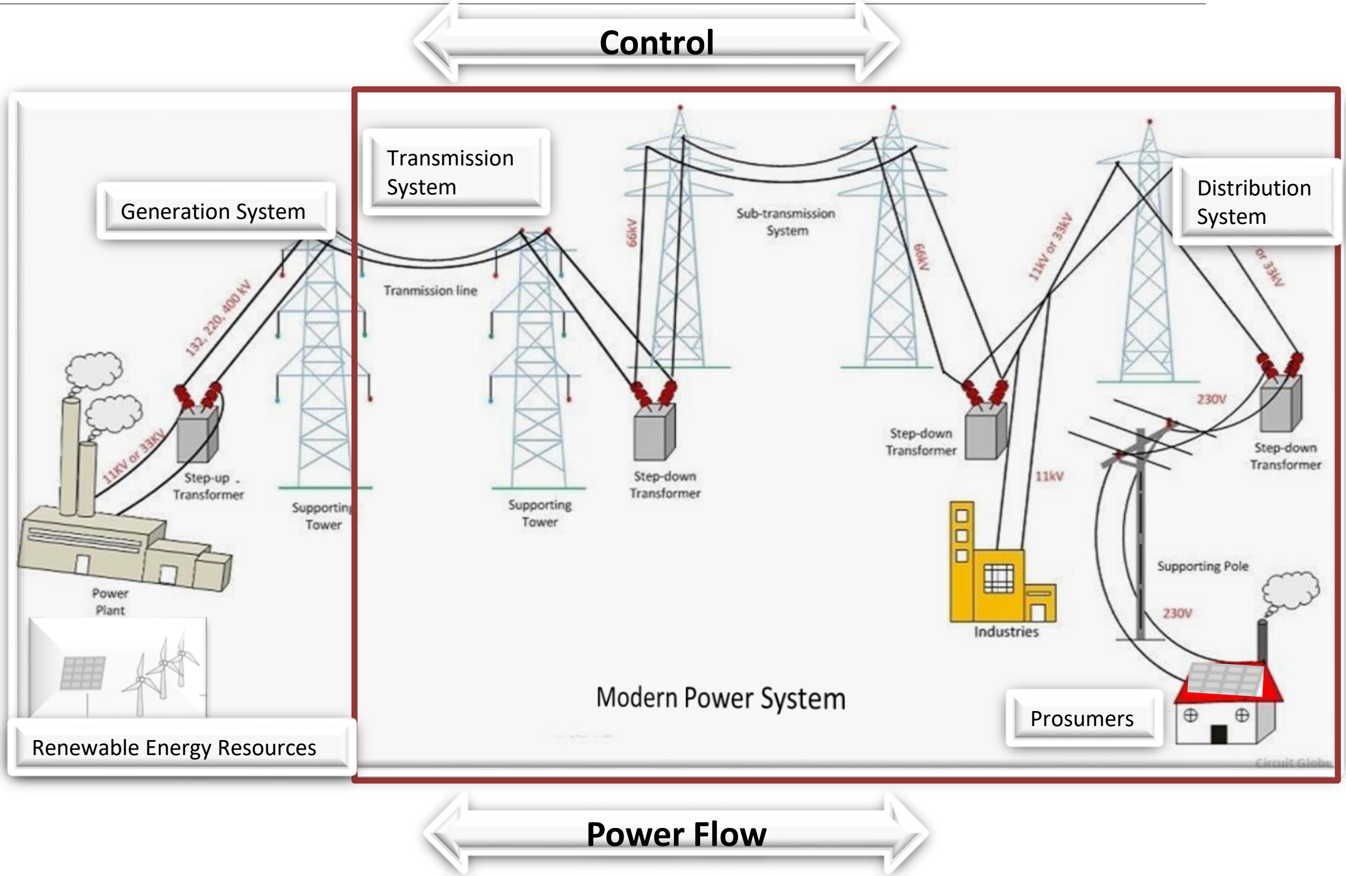
Challenges in Power System (As per NREL white paper):

- ➢ Reliable and Resilient System
- ➢ Economic Approach
- ➢ Investment for reliable and more resilient system
- ➢ System friendly renewable energy deployment

Focus of this Research:

- ➢ **Power System Operation and Planning Resilience**

Source: https://www.nrel.gov/docs/fy16osti/66482.pdf



Transmission and Distribution infrastructure are more fragile to environmental shock impacts

Power System Planning & Operation

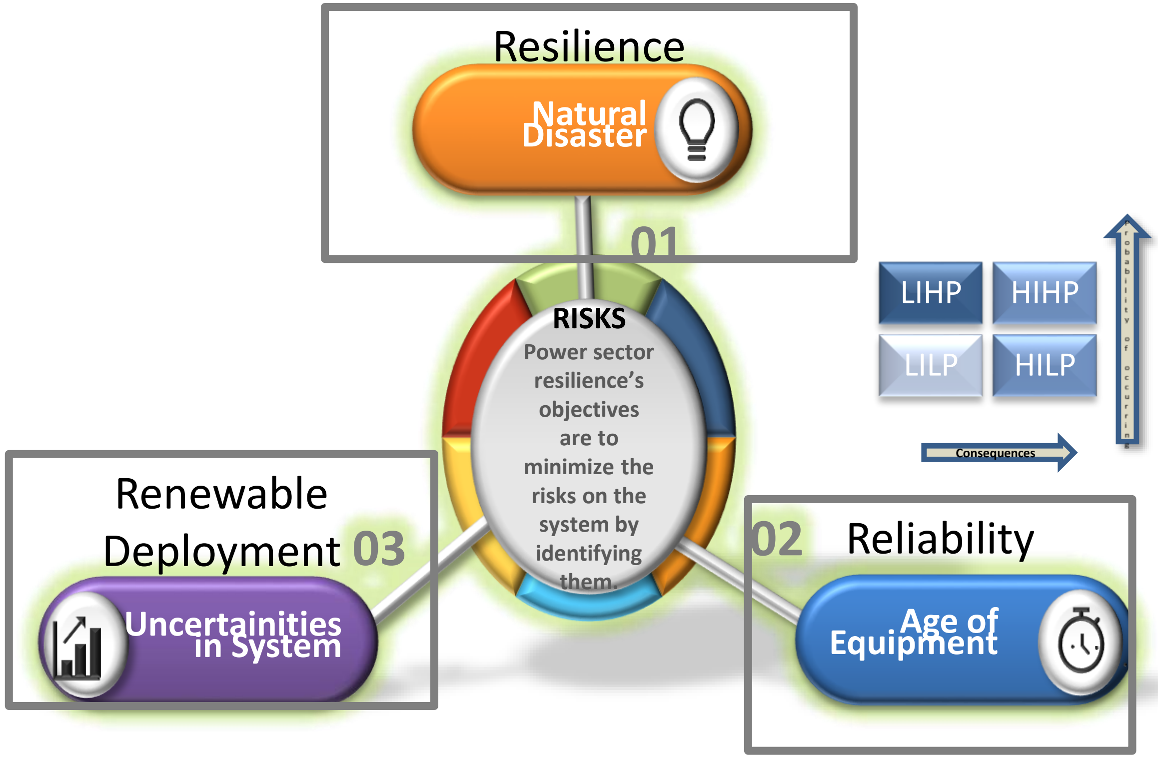
Power System Planning and Operation

Planning

- Generation and Transmission **expansion planning**
- **Risk Assessment**
- Renewables Integration

Operation

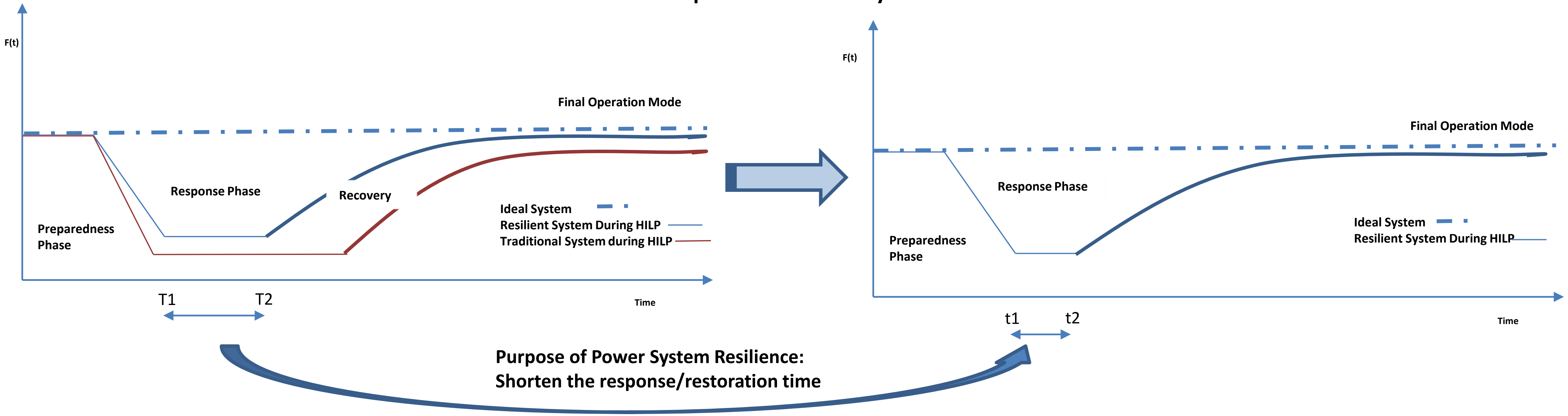
- Unit Commitment
- **Optimization for Energy Scheduling** & Operation Cost
- Security of supply



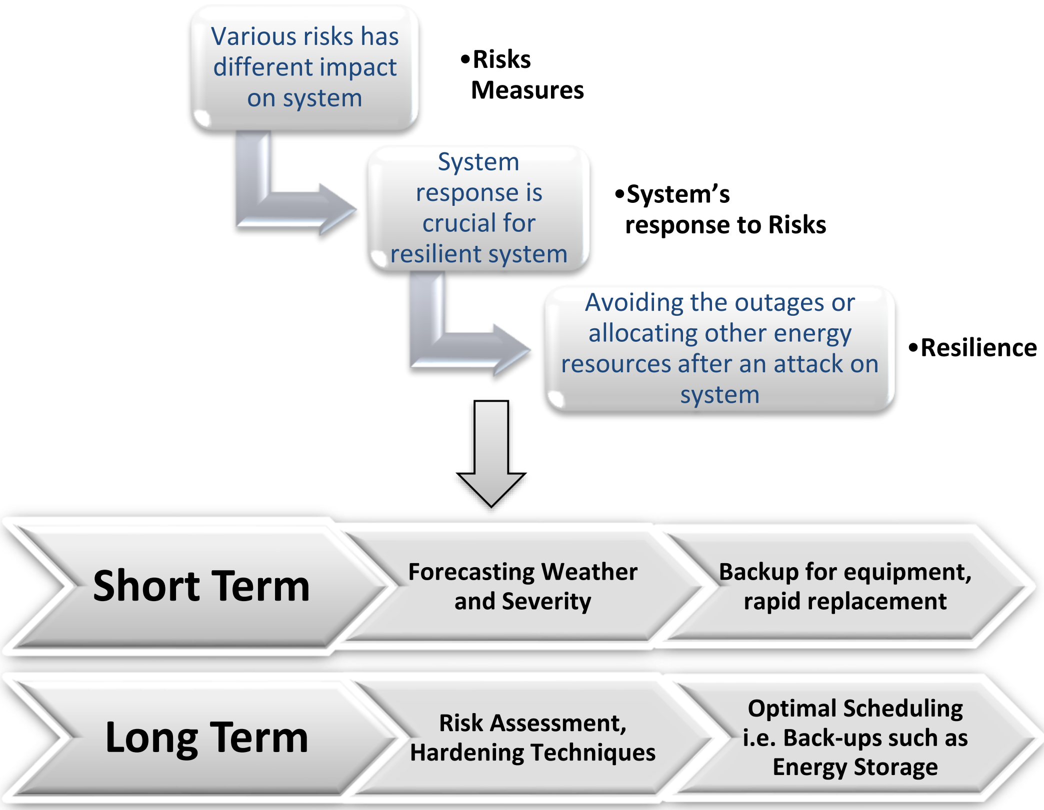
Risks Associated with Planning & Operation

Understanding Electric Power System Resilience

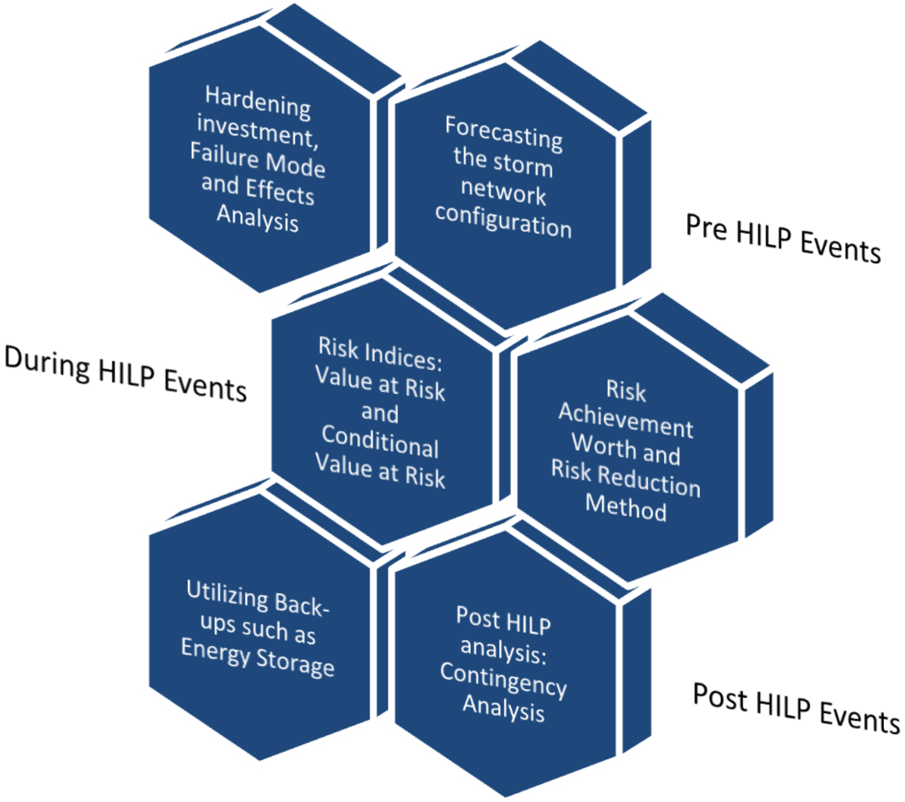
Resilience Trapezoid for Power System



Resilience Enhancing Techniques (Literature Review)



Resilience Strategies



Strategies for Enhancing Resilience for Pre, During and Post HILP

Objectives To Enhance the Resilience of Power System

Strengthen the System

Failure Analysis for System & Resilience Cost for hardening

Components and Load At Risk

Interdependencies of components in power system

Optimal Scheduling for DERs

Investment cost for Resilience of power system

Challenges

Research Objectives for Enhancing the Resilience of Power System

1. **Pre** Extreme Weather Events: **Infrastructure Hardening Plan**

Step:
1.1 Planning: Failure Mode and Effect Analysis & Failure Probability

2. **During** Extreme Weather Events: **System Analysis**

Steps:
2.1 Planning & Operation: Risk Achievement Worth (RAW) & Risk Reduction Worth (RRW) and CLaR & LaR
2.2 Operation: Contingency Analysis

3. **Post** Extreme Weather Events: **Back-up for critical load**

Step:
3.1 Operation: Scheduling Model for Back-ups as a Resilience Resource

Methodologies and Approach

Pre-HILP

Planning: Hardening Infrastructure-Resilience Risk Management Framework

Qualitative Methods
1. Disaster Assessment
2. Management Strategies for Pre, During and Post HILP

During & Post-HILP

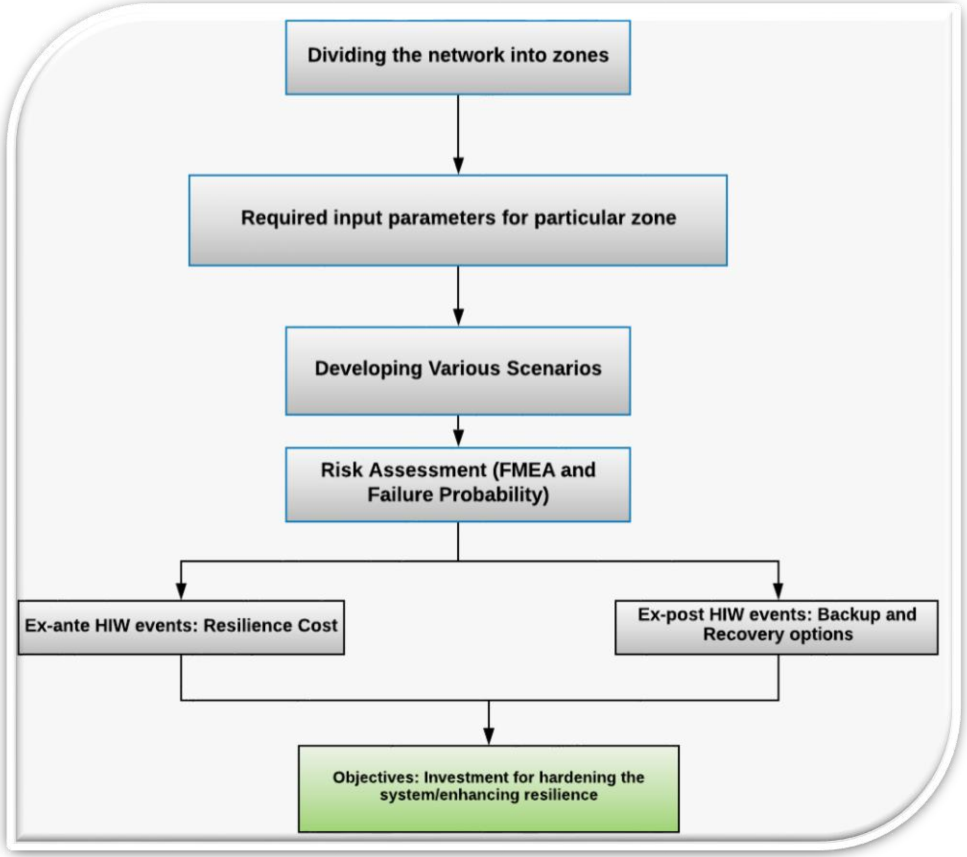
Operational: Power System Analysis & back-ups

Quantitative Methods
1. Statistical Methods
2. Analytical Risks i.e. RAW and RRW
3. Optimization

Methodologies for Enhancing the Resilience

NEW ZEALAND CASE STUDY: ASSESSMENT OF ELECTRICITY SYSTEM IMPACTS AND MANAGEMENT STRATEGIES PRE- AND POST- HIW EVENTS: NORTHLAND-AUCKLAND-WAIKATO WEATHER SCENARIO

Risk Management Proposed Framework (Pre-HILP)



Resilience Risk Management Proposed Framework (Pre-HILP)

- **Failure Mode and Effect Analysis**: Assess the relative impact of different failures.

$$\boldsymbol{Risk\ Priority\ Number = SEV(Severity) * Occurrence * Detection}$$

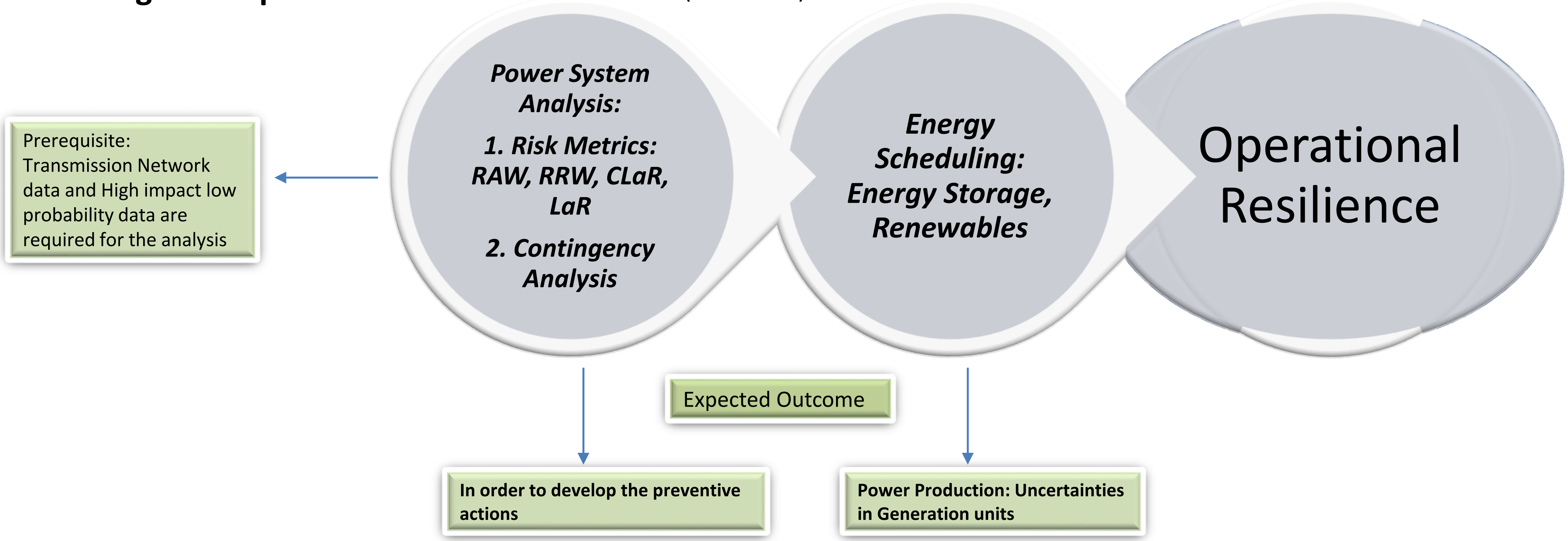
- **Probability of Failure**: Probability that a equipment might fail

$$\boldsymbol{Probability\ of\ failure = 1 - R(t)}$$

R(t)= Reliability of a equipment

Operation: Power System Resilience (During & Post-HILP)

1. **System Analysis** (During-HILP)
2. **Utilizing Back-ups as a Resilience Resources** (Post-HILP)



Operation: Power System Resilience

1. System Analysis (During-HILP)

- **Risk Metrics**: Used to identify the risks on load and component of system. Risk Achievement Worth (RAW), Risk Reduction Worth (RRW), Load at Risk (LaR), Conditional Load at Risk (CLaR)

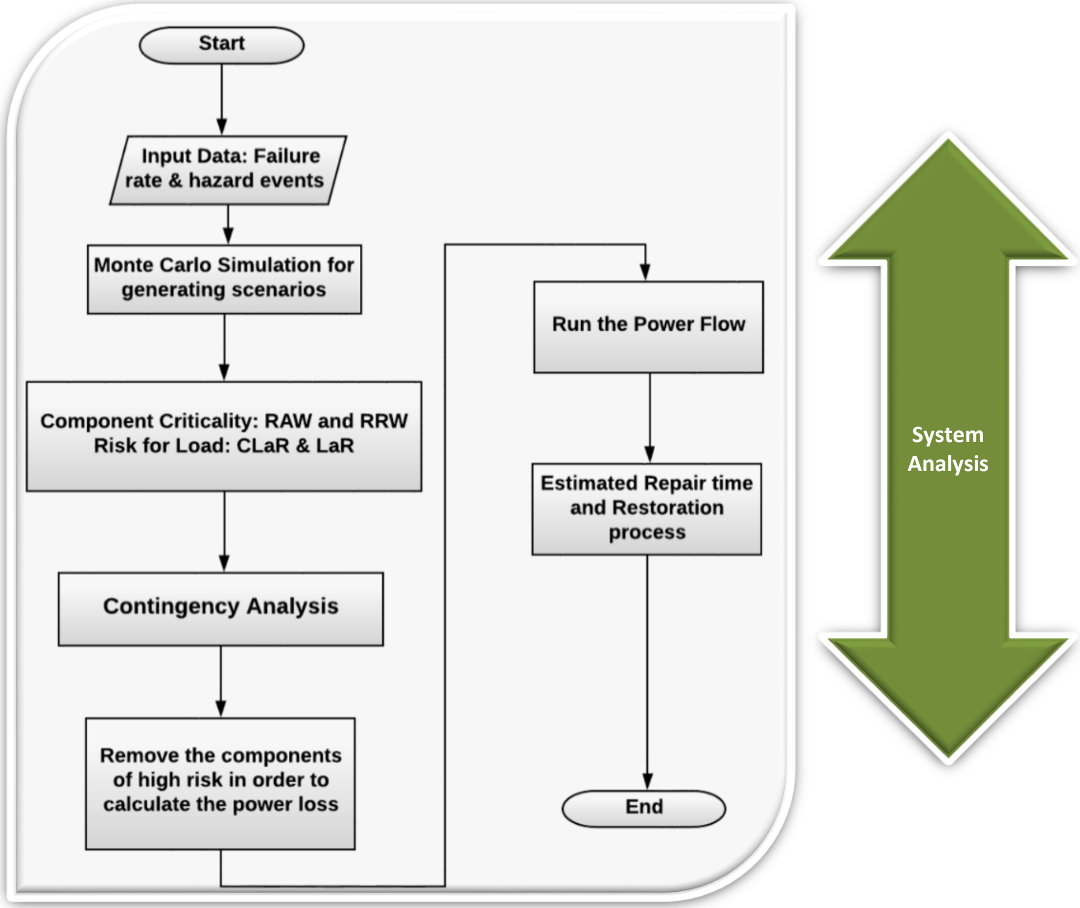
$$\boxed{RRW = (R_{base})/R(x=0) \qquad RAW = \frac{R(x=1)}{R_{base}}} \longrightarrow \textbf{Components at Risk}$$

$$\boxed{LaR = \min\{y : P_r(P_{loss} \le y) \ge \alpha\} \qquad CLaR(P_{loss}) = E\{P_{loss}, P_{loss} \ge LaR\}} \longrightarrow \textbf{Load at Risk}$$

- **Contingency Analysis**: if one equipment fails, this analysis calculate the over load on other equipment. It measures the violation.

2. Utilizing Back-ups as a Resilient Restoration Resources(Post-HILP)

- Energy: Traditional fuel backup resources, Energy Storage Systems, Renewables.
- Transmission & Distribution: Mobile-substation, Islanded Systems, Micro-grid, Back-feeding



Proposed System Analysis Methodology for During HILP Flowchart

NEW ZEALAND CASE STUDY*:* Assessment of Electricity System Impacts and Management Strategies Pre- and Post- HIW events: Northland-Auckland-Waikato Weather Scenario

Step 1: Weather Scenario Selection (Early 2021)

High Impact Weather Scenario selection will be done

Data From NIWA

Step 2: Network Modelling (Mid 2021)

Northland-Auckland-Waikato network has been given for the resilience assessment

Data From Transpower for outages

Step 3: Generating Scenario for Network

Scenarios needs to be developed based on the geographical location, season i.e. winter/summer and load demand

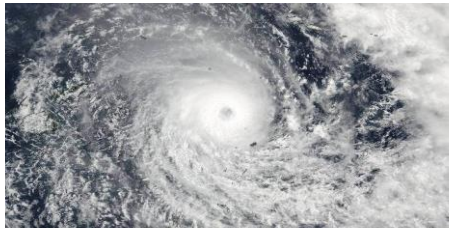
Step 4: Power Flow Contingency Analysis

Real Time Contingency: Network will be analysed based on the real data

Methodology to Conduct Case Study for Northland-Auckland-Waikato Electricity T&D Infrastructure

HIW Scenario Selection

Floods
Winter Storms: 2011, ’12, ’16, ‘19



NZ Cyclones: Victor, Los, Pam, Cook, Donna

Fires: Port Hills ’18 or Mt. Iron @’44

HIW Historical and Forecasted Events:
- Weather forecasting i.e. Temperature, wind, thunderstorm, hail etc.
- Frequency, duration, characteristics of HIW per year
- Intensity of hazard or HIW
- Data Sources: e.g. CF-netCDF, HYPACT, HYSPLIT

Proposed Tools:
- **Julia**
- **Python**
- **Matlab-Simulink**
- **Traditional Power system Analysis Softwares**

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Network Modelling

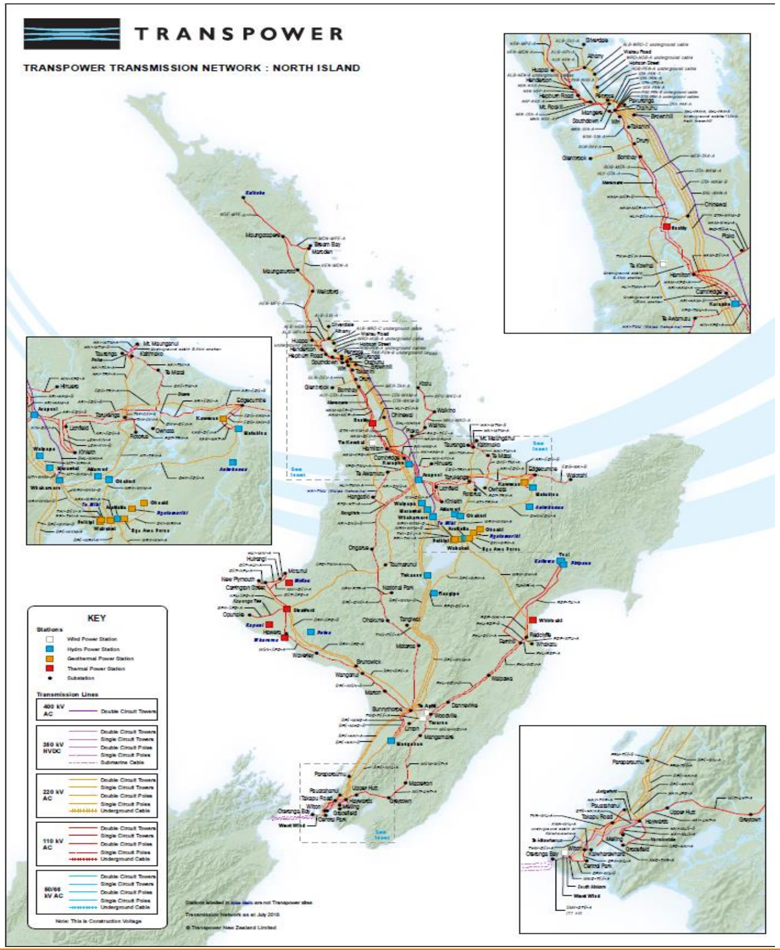
Network: Northland-Auckland-Waikato

Relevant NZ Electricity Network Data

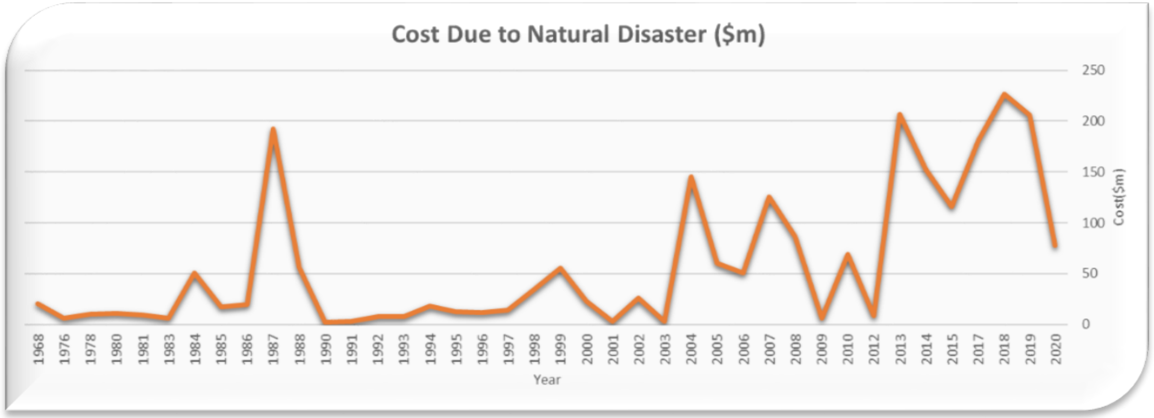
- Outages due to HIW
- Damages to electricity component and equipment
- Historical data for failure of equipment

Power System Analysis

- Failure mode effect analysis
- Probability of Failure
- Contingency Analysis
- Time to Repair



Economic Impact Assessment & Social Dynamics (Application Areas)



Cost of Natural Disaster Events from 1968 to 2020 in New Zealand

Resilience Cost:

- Initial investment to hardened the system
- Preventive cost and corrective cost
- Maintenance cost due to HIW

➕

Social Dynamics:

- Policies for enhancing the resilience
- Energy security and price uncertainty challenges
- Energy poverty

➕

Climate Adaptation:

- Adapting to change in climate, adjusting to actual and expected future climate

$$\boldsymbol{Resilience\ Cost = Preventive\ cost + Maintenance\ cost + Corrective\ cost + Optimal\ scheduling\ cost}$$

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