WECC Composite Load Flow Model

Course Project for EN304, under the guidance of

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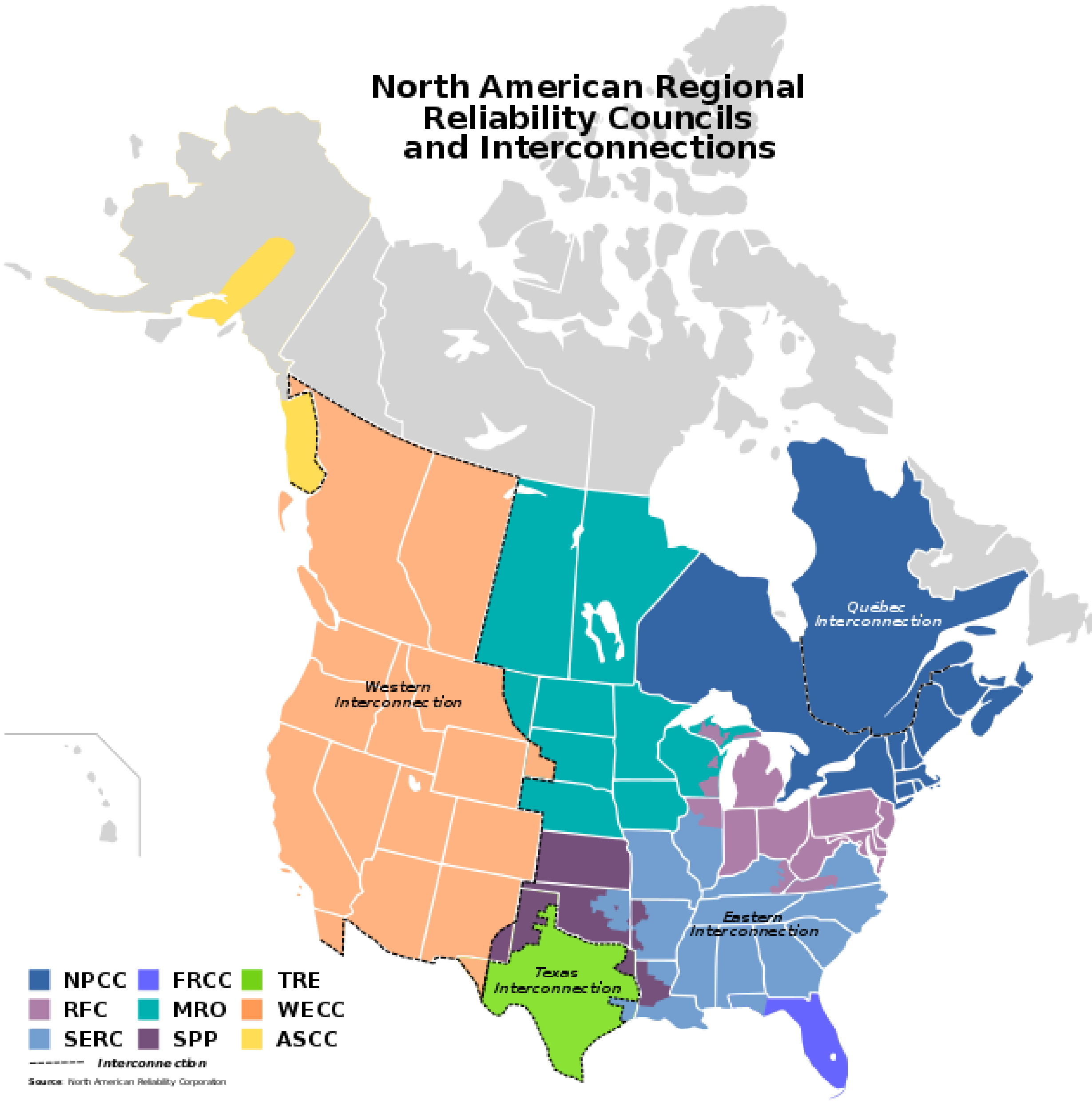
Overview

WECC (Western Electricity Coordinating Council) is the Regional Entity responsible for compliance monitoring and enforcement in the western region of the United States. Apart from that WECC develops Reliability standards for electricity operating and planning activities. Our current project is focused upon the WECC Dynamic composite load flow

Model (CMPLDW) specification. The objective of reliability guidelines is to provide information for issues regarding maintaining the BES's (Bulk Power system) reliability.



Goals

1. To understand Composite Load flow model specification, designed by WECC.
2. To learn composite load flow simulation software, here Power Factory
3. Simulate a section in the Bulk power system and analyse its dynamic behaviour

Dynamic Load Flow Modelling

The power grid is composed of several consumers who are independently consuming power from the BPS. An aggregate model of the end-user load is used for steady-state analysis as well as dynamic load. Dynamic load models are used to simulate aggregate load responses to the disturbances. It should model the general behaviour of the aggregate load while capturing the individual response accurately is not necessary. Here reasonable representation of the aggregate dynamic behaviour is critical for understanding the behaviour of the whole Bulk power system.

The earlier simulation of these events was unsuccessful with the frequency variation of induction motor load, and other types of loads which are sensitive to grid frequency and voltage. Eg. It was determined that an increase in induction motor load can degrade the oscillation damping ratio. It shows the importance of having an accurate representation of dynamic load models for stability analysis.

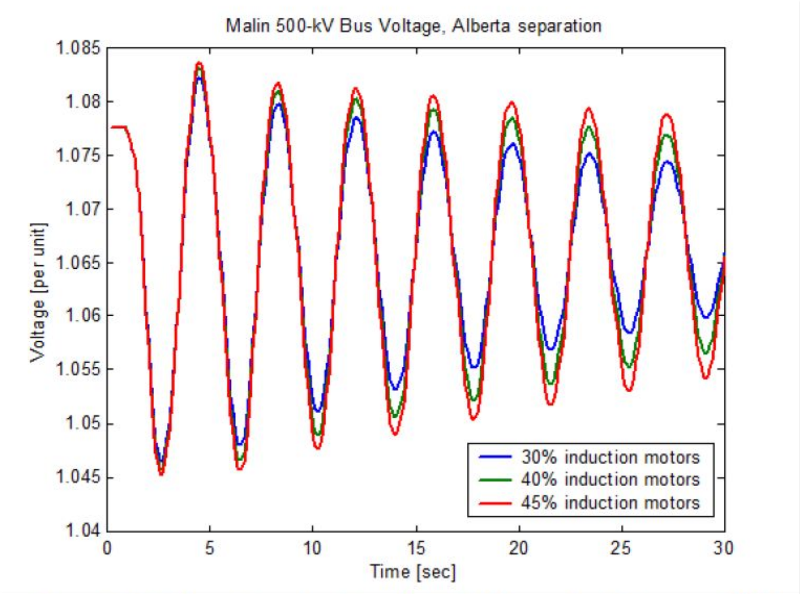


Figure 1.1: System Damping Sensitivity to Motor Load [Source: BPA]

The dynamic behaviour of the end-user load has a huge impact on the dynamic behaviour of the interconnected Bulk power system. E.g. Impact of the increased penetration of constant power load on voltage stability.

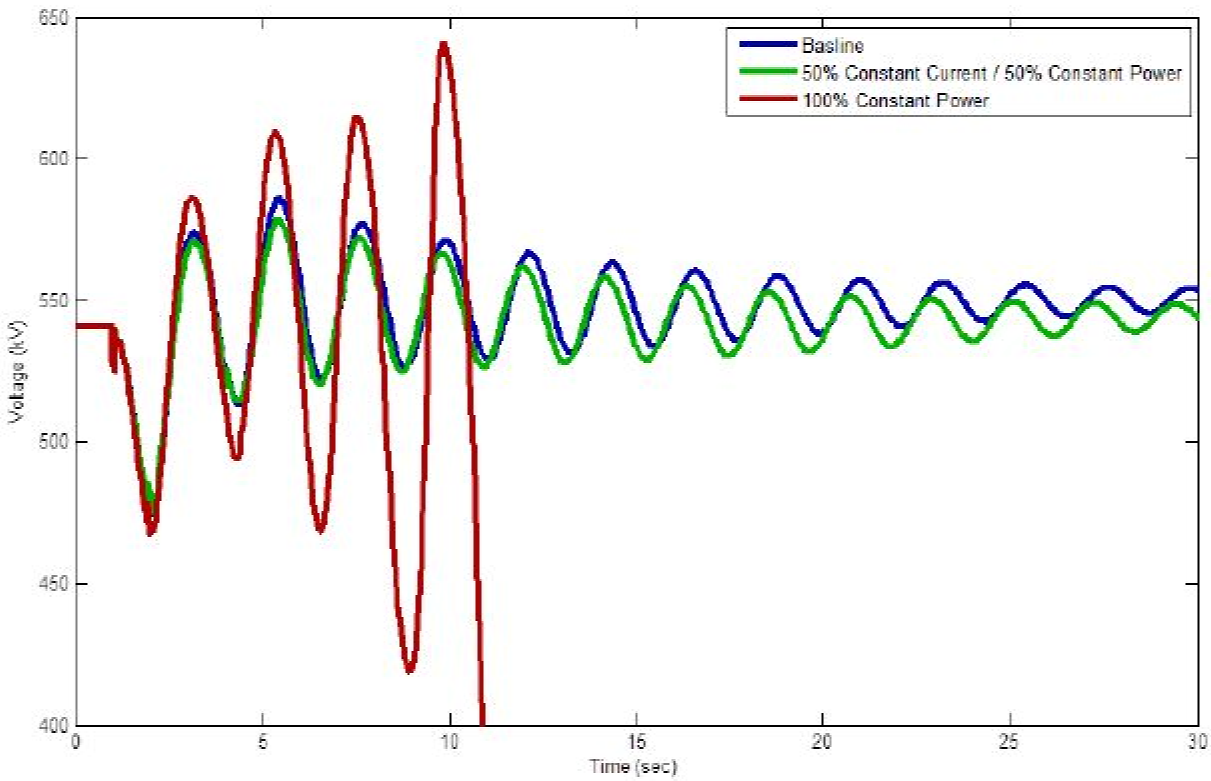


Figure 2.1: Impact of Constant Power Load on Oscillatory Stability [Source: WECC]

WECC model

Dynamic load modelling has been considered to be essential for power system stability studies. Considerable progress has been made in these fields from simple static load modelling to three-phase induction motor plus the ZIP model and then composite load model (CLM).

WECC CLM guidelines have been developed by NERC is one of the state-of-art, due to its capability for representing the diversity in the composition and dynamic characteristics of end-use loads and the electrical distance between its end-use and substations. These capabilities are essential to capture the stalling effects of the motor which lead to fault-induced delayed voltage recovery.

Structure of the WECC Composite load model

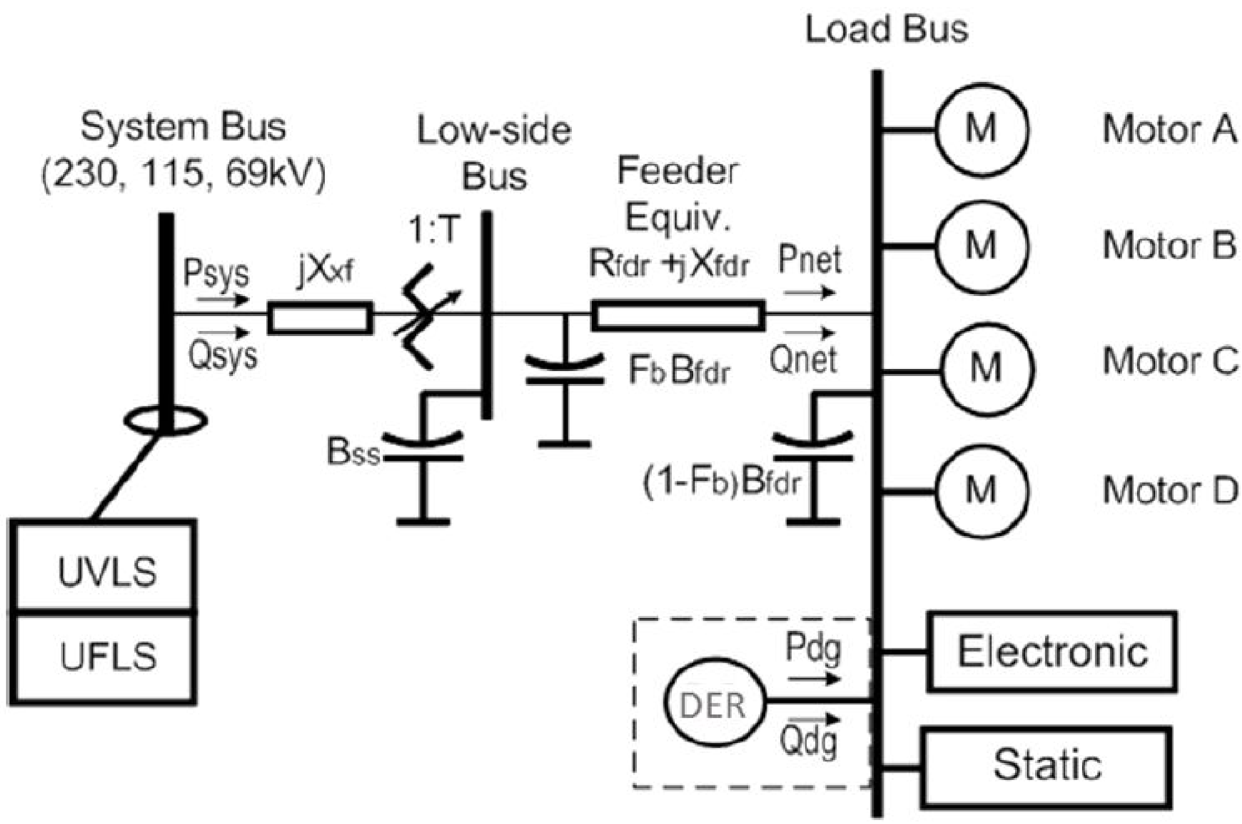


Figure 1.3: Composite Load Model Structure (CMPLDWG)

Step-down distribution transformer including under-load tap changer (ULTC) controls

• Low-side distribution system bus and end-use load bus

• Distribution equivalent circuit represented by a series impedance and shunt connected at the end-user load bus to represent rooftop PV and other small-scale distributed DER.compensation

• Induction motor models representing:

Motor A: three-phase, constant-torque compressors used in air conditioning and refrigeration

Motor B: three-phase higher inertia fans whose torque is proportional to speed squared

Motor C: three-phase lower inertia pumps whose torque is proportional to speed squared

Motor D: single-phase compressors, often used in residential air conditioning

• Power electronic load representing an aggregation of small electronic constant power loads

• Static load representing the remainder of unclassified aggregated loads

The latest iteration of the Composite Load Flow Model also includes distributed energy resources (DER)

Development of Dynamic Load component

Network Boundary Models of the Load components

Total four types of loads specified in the WECC CLM:

[Refer the earlier structure of the WECC composite model]

1. Three phase induction motor (motor A, B and C)
2. Single-phase induction motor (motor D)
3. Static load
4. Power electronic load

Proper network boundary model for interfacing the load components with the grid, this could be done by Norton equivalent model.

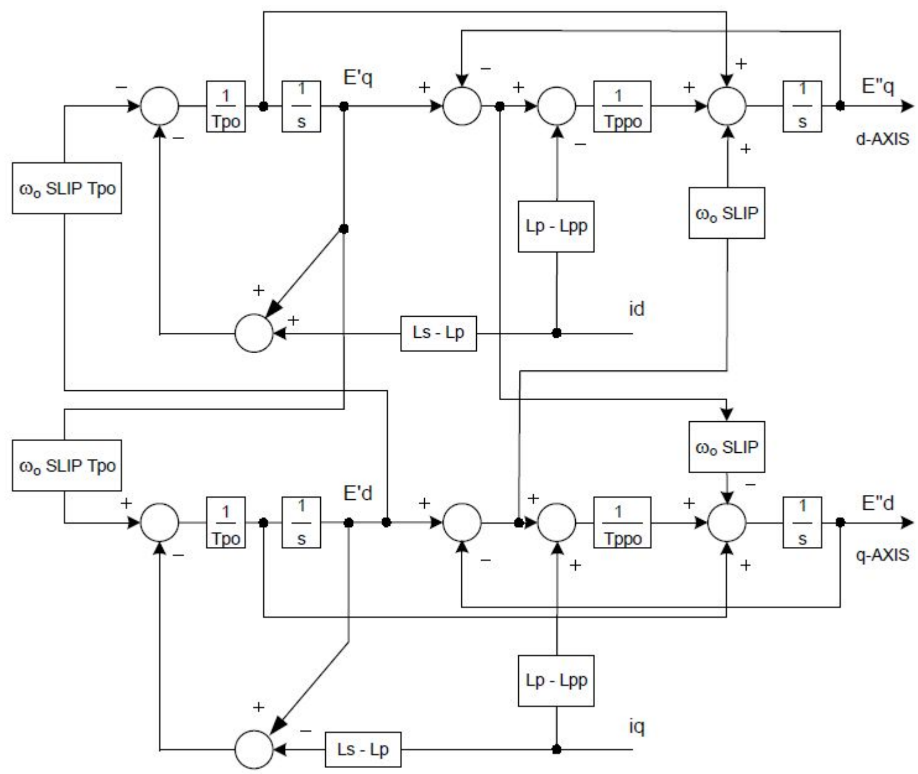
Key Steps for the Dynamic Load Components

1. Initialization
2. Differential Equation Integration
3. Current calculation
4. Post-Process

Three-Phase Induction Motor

A motor model for electro-mechanical transient analysis has been developed to represent in the WECC CLM.

Below is the block diagram model for a three-phase induction motor.



LFm -- Loading factor – used to set motor MVA base

Rs – Stator resistance (pu)

Ls – Synchronous reactance (pu)

Lp – Transient reactance (pu)

Lpp – Subtransient reactance (pu)

Tpo – Transient open circuit time constant (sec.)

Tppo – Subtransient open circuit time constant (sec.)

Here the four state variable are E_q', E_d', E_q'', E_d''

Single Phase Induction motor

These motors are very common in the residential application eg. Air conditioner compressors. Below is the control block diagram of it:

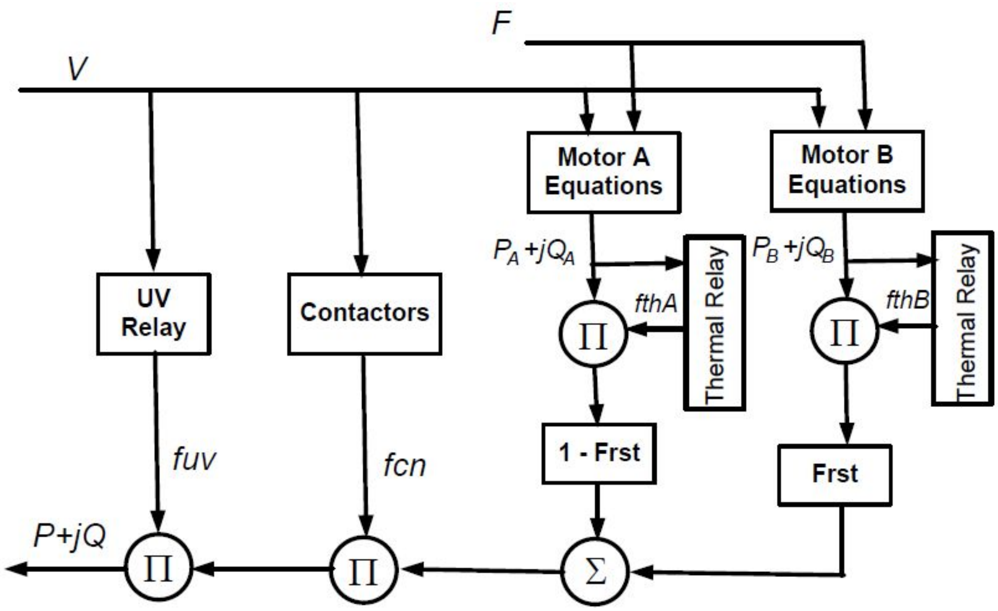


Figure 3 CMPLDW 1-Phase A/C Performance-based Model Schematic

Here motor A and motor B are two different types of single phase A/C motors used.

Motor A is "non-starting" A/C motors which couldn't restart the after stalling within the time frame of simulation. Whereas motor B is "starting type" which could quickly start after stalling.

Static Load Model

It is quite standard and similar that is used in the ZIP model i.e. that the load is divided into constant Power load, constant current load and constant impedance load.

Our Model

Our model is a representation of an industrial load, where single-phase AC motor and electronic loads are neglected. We have used the demo version of proprietary software PowerFactory by DIgSILENT, for all of our simulation and modelling work. Being a demo version the data export facilities were limited and the data are presented in separate files.

The model is connected to the grid with a 132 kV 3-phase busbar system. Then it is connected with a transformer of 132/33 KV, 90 MVA rating. Then the LV side of the transformer is connected to a transmission bus at 33 KV. From this bus, the 33 kV load bus is connected through a transmission line of 1 km length with the resistance of 0.1ohm and inductance of 1mH. Since the transmission line is only 1 km long, the shunt capacitance is neglected. At the transmission bus, there is a variable capacitor bank for reactive power compensation.

At the load bus, there is WECC modelled a motor is connected along with PV generation system and static load. The PV system injects 50 MW into the system. The motor consumes 50 MW and 10 Mvar of active and reactive power respectively. The static load has been modelled as a ZIP-model with 70% constant impedance and 30% constant current. The nominal power consumption of the load (rated at 33 kV) is 50 MW (active) and 10 Mvar (reactive).

Key Learnings:

We gained a thorough understanding of Dynamic Load flow and the specifications developed by WECC.

We carried out a load flow analysis for our industrial load model. We used new software - PowerFactory - with updated tools and electrical components in accordance with WECC specification.

Some of the key results we obtained:

1. Increase of capacitance bank reduces the voltage drop at subsequent buses
2. The resistive losses in the transformer is nearly independent of the voltage at the two buses.
3. Without PV generation, there is a drop in voltage (1 pu to 0.98 pu). There is also a significant reduction in power factor.

References:

Wecc.biz

Huang, Qiuhua, et al. "A Reference Implementation of WECC Composite Load Model in Matlab and GridPACK." arXiv preprint arXiv:1708.00939 (2017).

WECC Composite Load Model (CMPLDW) Benchmarking Summary

WECC Dynamic Composite Load Model (CMPLDW) Specifications

Reliability Guideline: Developing Load Model Composition Data