Enhancements for ORU's Future: Design for Automation and Effects on Storm Management

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Storm Impacts

Affecting Storm Response

- Storm management information
  - Prediction of types of outages, how many outages by type, where outages occur, how long to perform switching operations, how long to perform repairs, how long to restore power
- Protection system and manual switch design
- Automated switch design
- Automated analysis of switching operations
- Major storm and emergency preparation
  - Critical loads, missions, restoration based on missions

Weather Data for Predicting Outages

- Temperature
- Maximum wind speed
- Lightning data
- Storm radar data
  - Refine existing outage models so that outages for a given storm type become a function of local weather conditions
  - Provides important weather variables and weather conditions not previously used – hail, precipitation intensity, storm intensity, micro bursts, etc.
  - Provides extent of storm for more accurate statistical models and more accurate real-time predictions
  - Provides for weather based storm detection

(Temperature, Maximum wind speed, Lightning data: Current ORU Outage Models)

Modeling of Lightning Outages

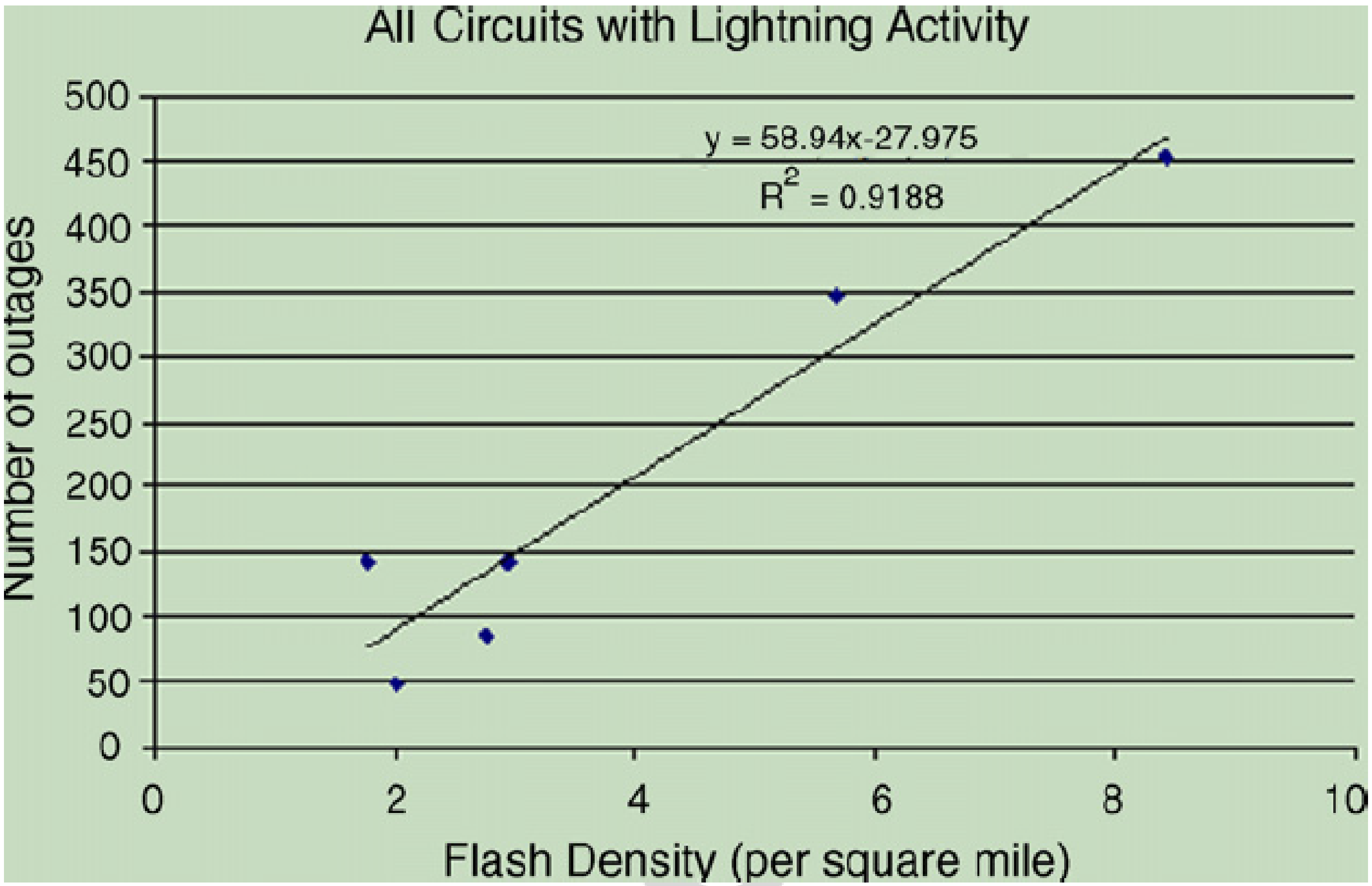


Fig. 10. Number of power outages vs. 10–30 kA flash densities in 200-ft corridor over all circuits with lightning activity.

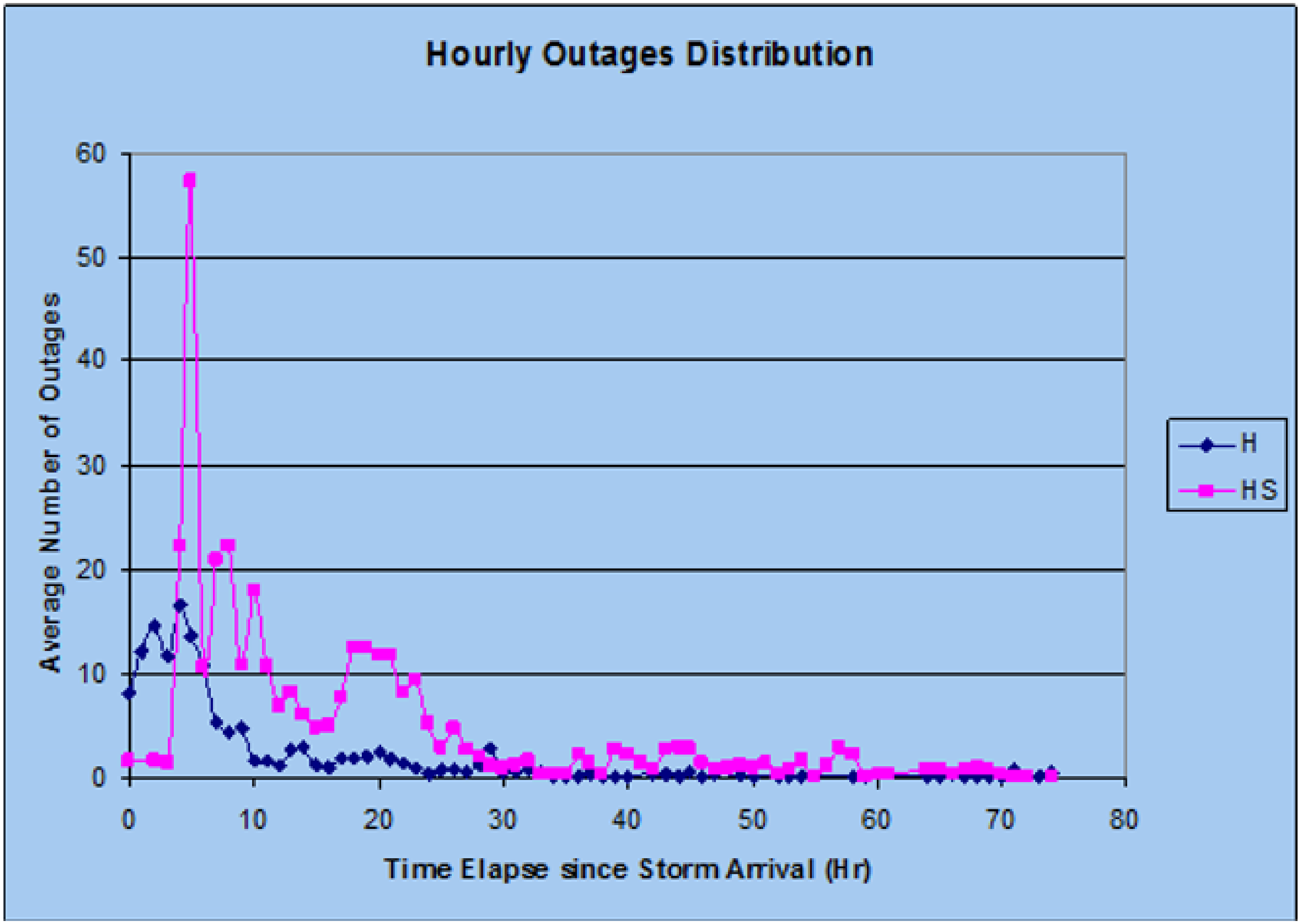
Storm Outage Estimates with Radar

- Based upon storm type, weather conditions are categorized, say weather condition 1, weather condition 2, etc. in the circuit corridor
  - Weather condition = { temperature, wind speed, flash density, precipitation intensity, hail index, storm intensity, etc. }
- For given storm, determine numbers of equipment by type affected by each weather condition, along with duration of exposures
- Using expected % failures for equipment types and weather conditions, estimate outages

Monte Carlo Storm Analysis

- Expected failures by equipment type as a function of hour of storm
- Automated, reconfiguration for restoration collaborating with power flow (manual switching or automatic switching or both)
  - Time varying loads (load research, monthly kWHr, hourly kWHr, load growth)
- Crew operation models
  - Numbers of each crew type, what crews can repair what failures, times to operate switches, times to perform repairs by failure type
- Customers and customer types
  - Critical customers and/or critical loads; prioritized missions, which may be groups of critical customers and/or critical loads

Outage Distributions for Monte Carlo Analysis



Failure Distributions for Monte Carlo Analysis

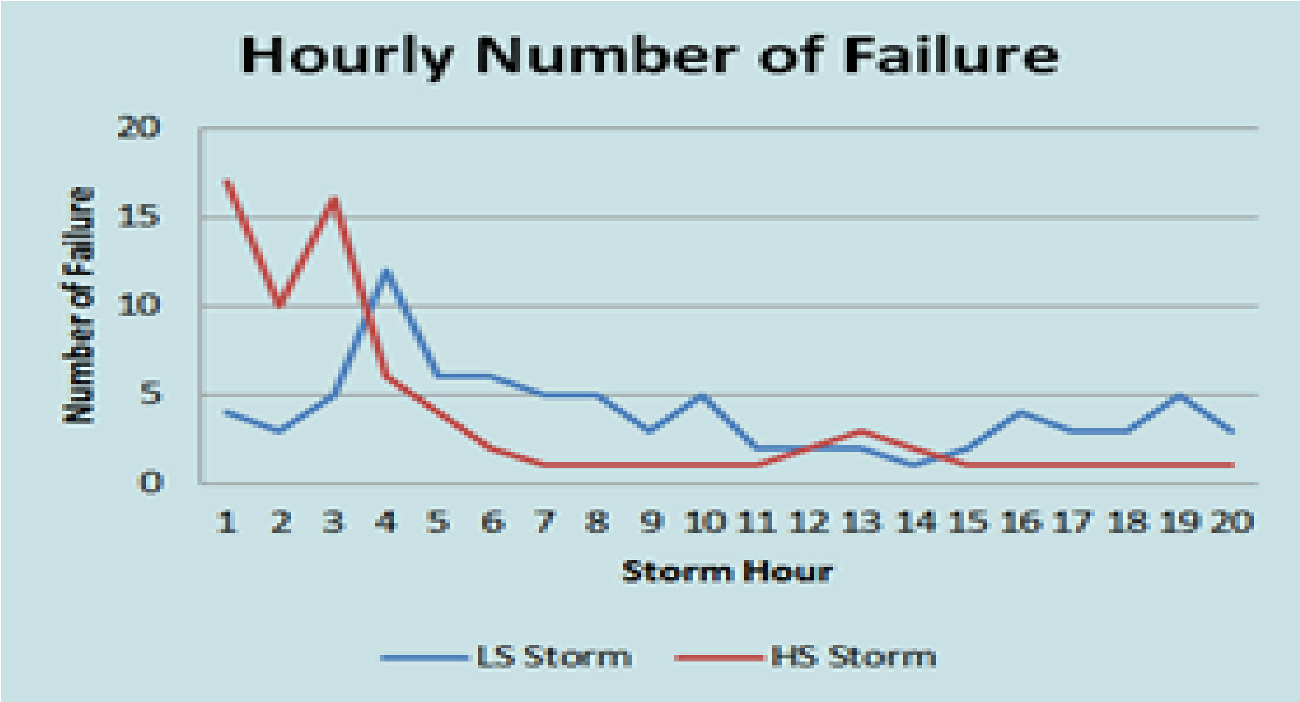


Fig. 3.1. Average Hourly Number of Failures for Low Temperature, Storm Wind (LS) and High Temperature, Strong Wind (HS) Type Storms

Manual Model Versus Automated Model

Significant size system needed to test reconfiguration capabilities

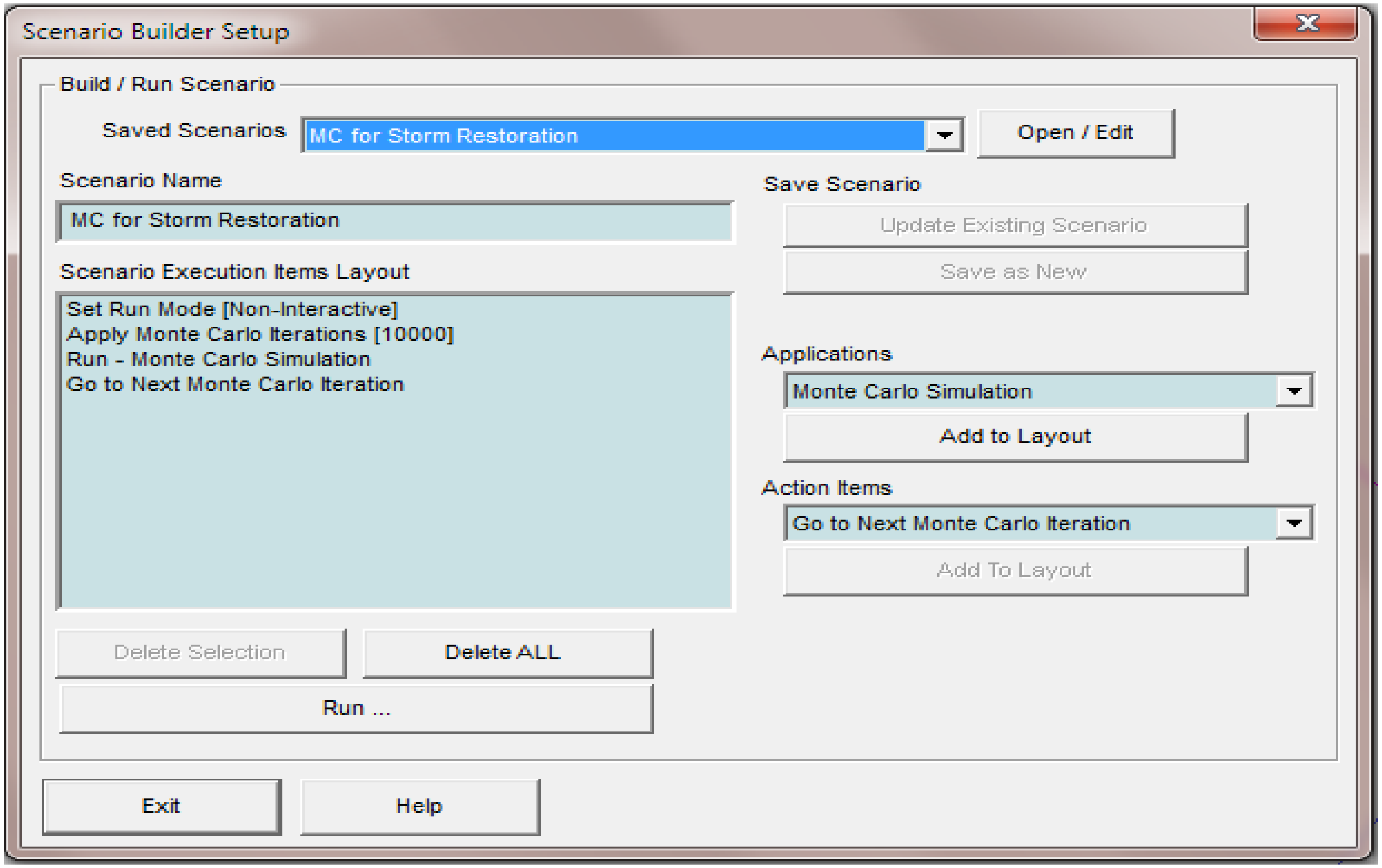
Model Components

Component Type	Numbers for 14 Feeder Model
Primary Overhead Line	6027
Overhead Line Cutout	828
Overhead Distribution Transformer	2148
Overhead Step Transformer	14
Voltage Regulator	1
Recloser	78
Switched Capacitor	12
Fixed Capacitor	16
GOAB	45
Disconnect Switches	286
Underground Cable (Primary)	2917
Underground Distribution Transformer	1292
Underground switches	32
Busses (transmission/distribution)	8
Transformer (transmission/distribution)	15
Breaker/ switch (transmission/distribution)	8

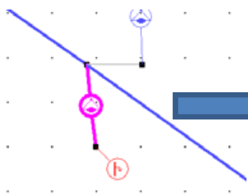
Customers Modeled

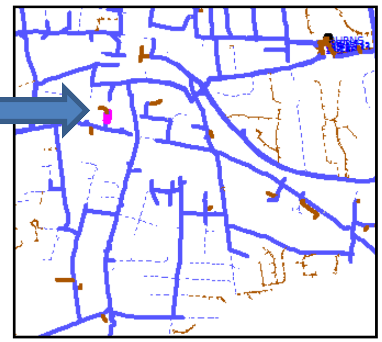
Class Name	Customer Numbers for 14 Feeder Model
Residential-1	19196
Residential -2	18
Residential -3	13
Small Commercial Type 1	2079
Small Commercial Type H	81
Large Commercial Type 1	506
Traffic Light- 100W	4
Single Large Load Type 1	86
Single Large Load Type 2	8
Total Number of Customer	21991

Monte Carlo Scenario

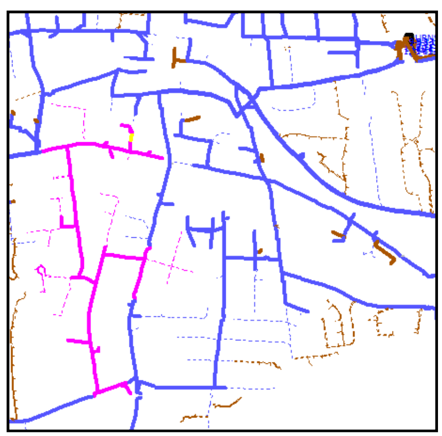


12 Manual for Every 1 Automated?

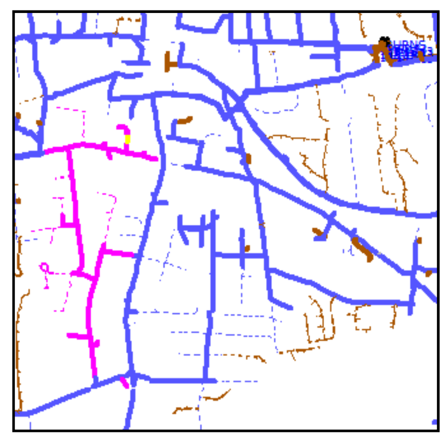




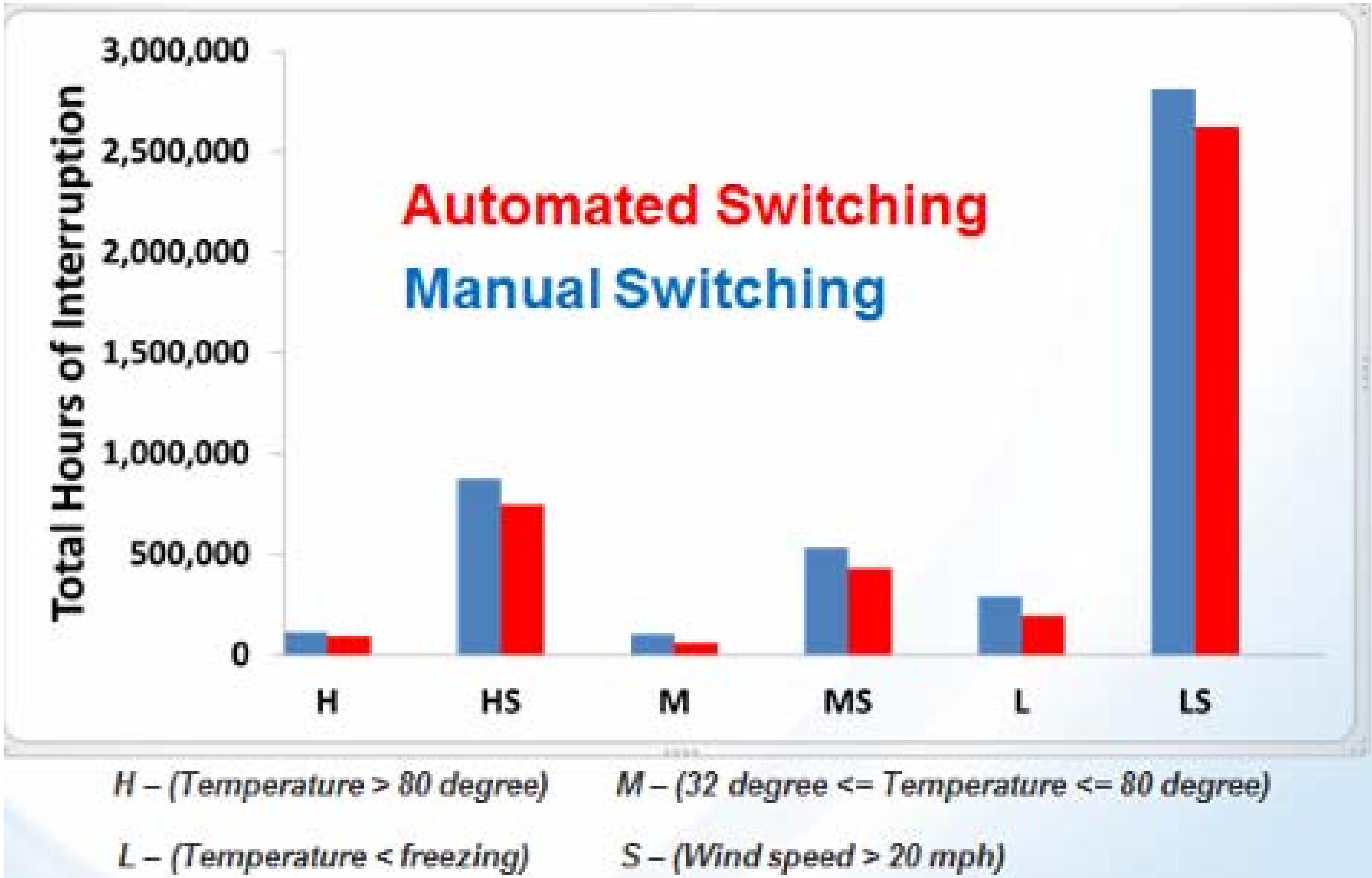
Reconfiguration for Restoration
- 3 auto switch operations
- 63 customers in outage



Reconfiguration for Restoration
- 9 manual switch operations
- 51 customers in outage



Storm Analysis Results



SAIDI Improvements

		Manual Circuit		Automated Circuit	SAIDI Improvement
Type of Storm	Average Number of Failure per Storm	Device Switching Hour	Total Customer Outage Time	Total Customer Outage Time	%
H	18	40	113,674	95,859	0.4051
HS	96	213	874,317	745,988	2.9178
M	27	60	103,662	60,925	0.9717
MS	74	168	531,059	431,580	2.2618
L	55	132	301,707	197,353	2.3727
LS	173	403	2,812,471	2,623,756	4.2907

DOE Goals

- Power should be maintained to 98% of critical customers
  - DOE goals do not consider missions
- 50% load losses prevented
- 50% reduction in restoration time

Grid Resiliency for Missions

- Critical customer power loss may be automatically reported at a utility, but determining how to restore power is not supported by automated analysis
- Missions and mission critical loads
  - Public safety: live wire down, broken poles, or precariously hanging trees or equipment
  - Critical loads: Major economic impact; Transportation-traffic lights, gas stations, subways, railroads; Fire fighting; Potable water supply; Health services - pharmacies
- ***Including critical customers and missions in ORU ISM will enable design and operational algorithms to address emergency management (major storms)***

Comparing Alternative Designs

- For a given set of events, Design A is more resilient than Design B if Design A results in better { customer, critical customer, critical load, mission } restoration/resiliency metrics on average than Design B
- Define restoration vector which contains restoration and/or system resiliency metrics that may be used to compare alternatives
- Compare performance from different Monte Carlo runs across different designs against events, using Monte Carlo events from Monte Carlo run on base case system
  - Monte Carlo event performance comparison runs
- Incrementally compare performance of design improvements

Restoration Vector

- Customers and critical customers outaged after protective device operations
  - Note, critical customers may be grouped by prioritized missions
- Customers and critical customers outaged after auto devices operate
- Customers and critical customers outaged after manual operations
- CAIDI for customers and critical customers
- Total customer outage times

Restoration Vector Indices

- Subscript d = system “d”, where the performance of different systems will be compared (often base case is d = 1)
- Subscript i = event “i,” defines a set of failures that result in customer power outages
  - 100,000’s of events simulated over many storms/years
- Subscript o = manual switch operation “o,” where for a given event manual switch operations are ordered by index o
- Subscript m = mission “m,” where there may be multiple missions and missions are prioritized

Restoration Vector

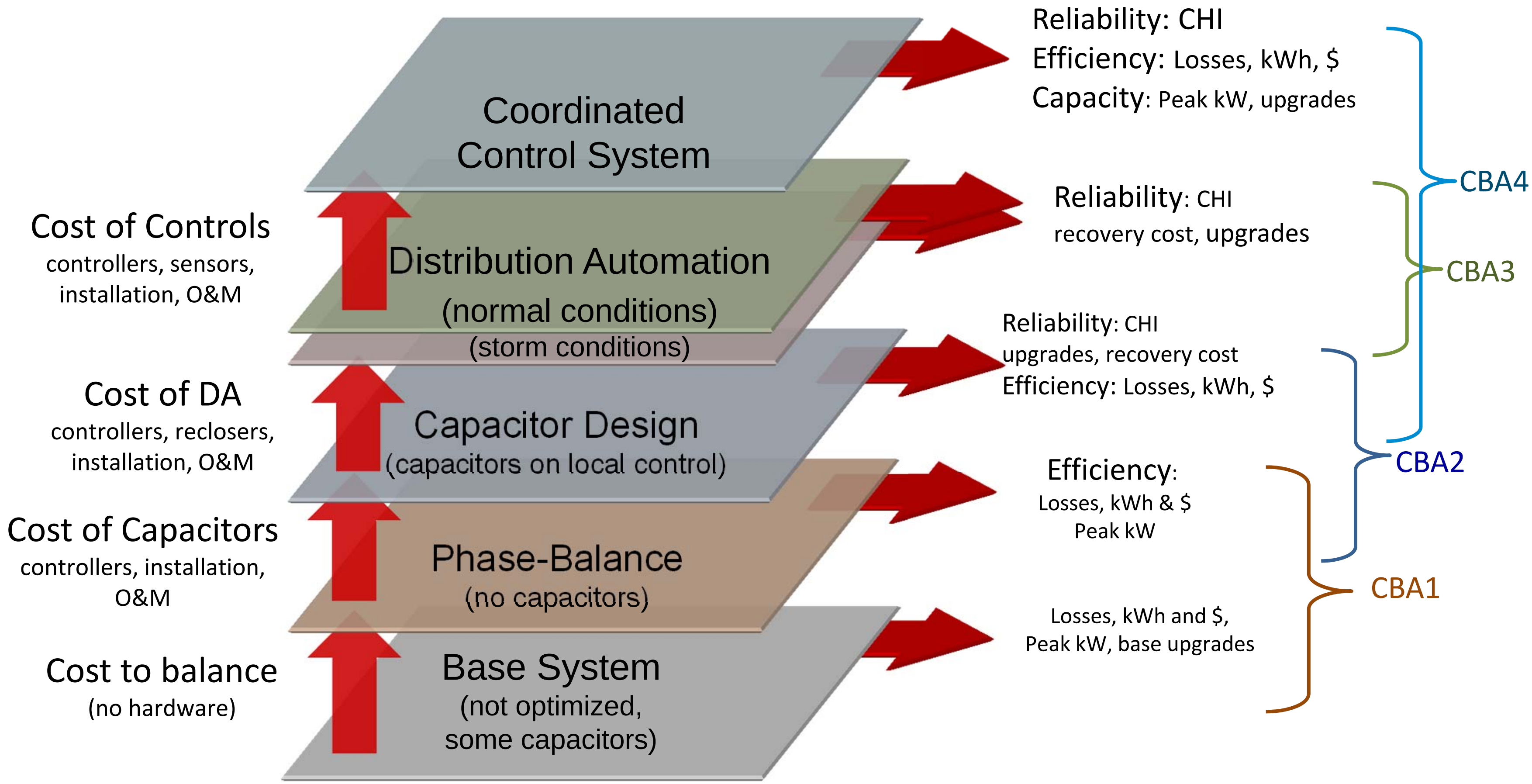
r_{di} = {C_{RAdi}/C_{OPdi} , C_{RMdio}/C_{OPdi} , T_{dio} , T_{REPdi} , $CAIDI_{di}$, $TCOH_{di}$, N_F, N_P, N_A, N_{MAN}, N_{MIS}, list(failed equipment), list(protective devices), list(auto switches), list(manual switches), list(crew types), list(crew type repair times), T_{RESdi}, …, list(mission priorities), CC_{RAdmi}/CC_{OPdmi} , CC_{RMdmio}/CC_{OPdmi} , $CCAIDI_{dmi}$, $TCCOH_{dmi}$,… ,

o = 1, 2, …, N_M, m = 1, 2, …, N_{MIS}}

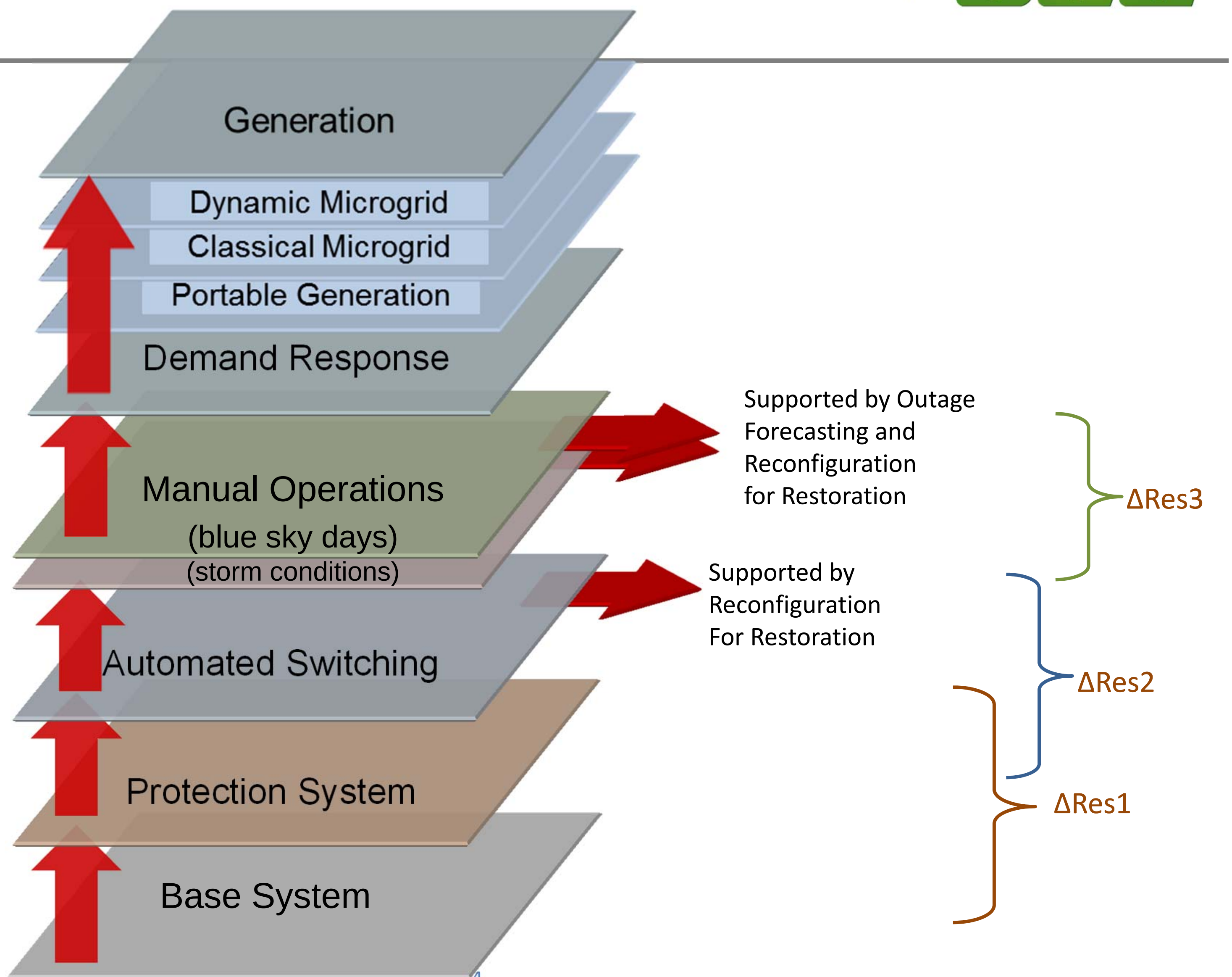
Compare performance of alternative designs by plotting restoration vector quantities, such as plotting variable values corresponding to d and/or m against i

Note: ORU capability for blue-sky-days

Incremental CBA Analysis



Incremental Restoration/Resiliency Analysis



Customer Count Definitions

- For event i, for system d, define
  - C_{OPdi} = number of customers outaged when protective devices operate
  - C_{OAdi} (C_{RAdi})= number of customers outaged (restored) following operation of automated devices
  - C_{OMdio} (C_{RMdio}) = number of customers outaged (restored) following operation of manual device o

Mission Critical Customer Count Definitions

For event i, for system d, for mission m, define

- CC_{OPdmi} = number of critical customers outaged when protective devices operate
- CC_{OAdmi} (CC_{RAdmi})= number of critical customers outaged (restored) following operation of automated devices
- CC_{OMdmio} (CC_{RMdmio}) = number of critical customers outaged (restored) following operation of manual device o

Restoration Vector Definitions

$TCOH_{di}$ = total customer outage hours

$TCCOH_{dmi}$ = total critical customer outage hours

T_{di1} = time required to operate first manual switch measured from protective device(s) operation

T_{dio} = time between operating manual switch o - 1 and manual switch o, o > 1

T_{REPdi} = time to perform repairs measured from time of final manual switch operation

T_{RESdi} = total time required to restore all customer power measured from protective device(s) operation

N_F, N_P, N_A, N_{MAN}, N_{MIS} = count of failed equipment, protective device operations, automated switch operations, manual switch operations, missions, respectively

Calculating $CAIDI_{di}$,$CCAIDI_{dmi}$

($CCAIDI_{dmi}$) $CAIDI_{di}$ = (Critical) Customer average interruption duration interval

$$CAIDI_{di} = (C_{OAdi} * T_{di1} + \text{sum}(C_{OMdij} * T_{dio} , o = 2 \text{ to } N_M - 1, j = o - 1) + C_{OMdio}(o = N_M) * T_{Rdi}) / C_{OPdi}$$

$$CCAIDI_{dmi} = (CC_{OAdmi} * T_{di1} + \text{sum}(CC_{OMdimj} * T_{dio} , o = 2 \text{ to } N_M - 1, j = o - 1) + CC_{OMdimo}(o = N_M) * T_{Rdi}) / CC_{OPdmi}$$

Analysis Automation with ISM

- ORU power flow solution, transmission to every distribution secondary, every 4 seconds
- ISM automated analysis and design – phase balancing, capacitor design, switch placement, feeder performance, Monte Carlo analysis with reconfiguration for restoration, comparisons of alternatives
  - Customer load data, load growth, SCADA data, weather data (temperature, lightning, radar), storm equipment failure models, storm outage models, crew models, …

Conclusions

- Use of historical radar data will help improve outage models
- Use of real-time radar data will help a utility detect storms and provide greatly improved, real-time outage forecasting, including pinpointing of severe outage locations
- Automation can make better use of existing plant capacity during both non-storm and storm events
- Utilities need to build models needed for analysis and design of automated systems

ORU Current Outage Estimation

- Weather conditions (temperature range and maximum wind speed) are used to select curve fit to use of expected outages as a function of the hour of the storm type
- The expected outages are modified every 15 minutes by using error between predicted outages and actual outages to update predicted outages

Short Comings of Current Outage Estimation Approach

- For a storm that does not cover the whole service territory no way to accurately calculate the equipment affected
  - This affects development of statistical models
  - This affects real-time predictions
- The current correlation between storm type and outages does not take into account any variations in weather conditions across the system

Short Comings Continued

- Just takes into account wind and temperature and does not take into account other weather conditions that probability have significant affects on equipment failures
- Does not predict where outages will occur

Envisioned Benefits of Radar Data: 1

- Provides timely and accurate detection of the presence of a storm
- Provides extent of storm
  - For each equipment type, provides ability to calculate amount of equipment affected by storm
- Provides historical weather conditions for each individual piece of equipment
  - Needed for developing fine grained, detailed models of weather affects on equipment failures

Envisioned Benefits of Radar Data: 2

- Provides real-time (eg, 5 minute sample interval) weather conditions for each individual piece of equipment
  - Update outage estimates as storm progresses
  - Estimate outages on an individual substation/feeder system basis, helping to determine where crews will be needed

Envisioned Benefits of Radar Data: 3

- Increases fidelity of outage model
  - Brings in measurements of important variables that probably have significant affects on equipment failures – precipitation intensity, hail
  - Provides a distributed model
- For a given type of storm, estimate outages as a function of local weather conditions
- Provides better models for testing performance of alternative designs against storm conditions