BC HYDRO EXPERIENCE WITH PSEUDO MEASUREMENTS IN STATE ESTIMATION

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INTRODUCTION

- Network model characteristics
- Measurement model overview
- Load model overview
- Overview of BC Hydro state estimator implementation
- **Load allocation methodology**
- Impact on state estimator solution quality
- Utilization of branch pseudo measurements
- Conclusions

NETWORK MODEL CHARACTERISTICS

- Network model comprises 2500 buses, 386 generators, 1126 loads
- Includes detailed model of BC Hydro control areas and approximate models of BPA and TAU areas
- Voltage levels from 500kV down to 25kV and 12kV feeder heads
- Large portion of 60kv network is modeled in detail
- Presence of lines with high r/x ratio
- Customized HVDC model

MEASUREMENT MODEL OVERVIEW

- Redundant telemetry in 500kv and portions of 230kV network
- Unobservable areas in parts of 230kV, 138kv, 60kV and 25kV networks
- Large unobservable areas in external networks
- Large number of current measurements
- Significant number of summed measurements

LOAD MODEL OVERVIEW

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- ZIP load model (constant impedance, constant current, constant power)
- Load lumped at low voltage buses of distribution transformers (60 kV, 25KV and 12KV)
- Loads not directly measured
- Most of the loads located in network areas that are un-observable or weakly observable
- Presence of loads that consume reactive power

STATE ESTIMATOR IMPLEMENTATION

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- State estimation is executed in three steps
- Pre-se power flow
- State estimator (RTNET)
- Post-se power flow

- Pre-SE power flow is run with the objective to:
  – Provide better initial condition
  – Provide values for branch pseudo measurements
  – Determine the ratio for split of summed measurements over components

- Pre-SE power flow relies on the following inputs:
  – Real-time switch statuses
  – Real-time analog measurements of generator MW outputs and bus voltage magnitudes
  – Allocated MW and MVAR loads

- Post-SE power flow is run with the objective to:
  - Refine the solution after re-distribution of bus mismatches
  - Verify the feasibility of state estimator result
- Post-SE power flow relies on the following inputs:
  - State estimator solution
  - All controls are disabled in order to preserve the solution close to original state estimator result

LOAD ALLOCATION METHODOLOGY

BC hydro

- Each BC Hydro load is allocated in real-time before the execution of pre-SE power flow
- Load allocation factors are used to split the total BC Hydro control area load to individual loads
- Hourly schedule of load allocation factors (both MW and power factor) for regular week days plus holidays is assigned to each load in the area

LOAD ALLOCATION METHODOLOGY

- Total control area load is calculated by AGC in real-time in every AGC cycle (4 seconds) based on:
  - Real-time measurements of generator MW outputs and tie-lines
  - Total area MW loss calculated in previous state estimator run
- The calculation of load allocation factors is performed on the external server
- Hourly schedules for all loads for the entire week are uploaded to EMS every Monday at 10am
- State estimator processes the schedules in every run to allocate loads before pre-SE power flow executes

LOAD ALLOCATION METHODOLOGY

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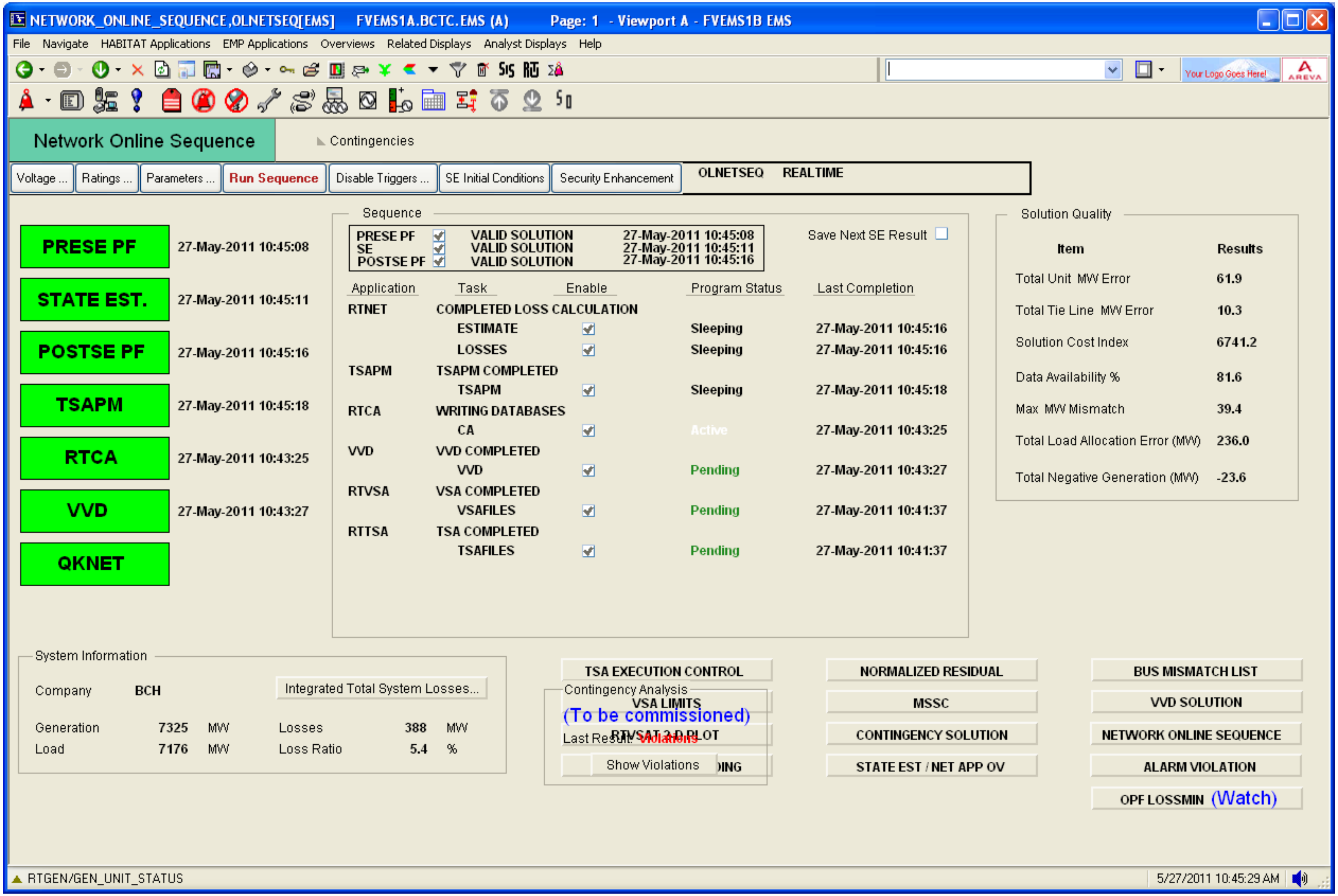
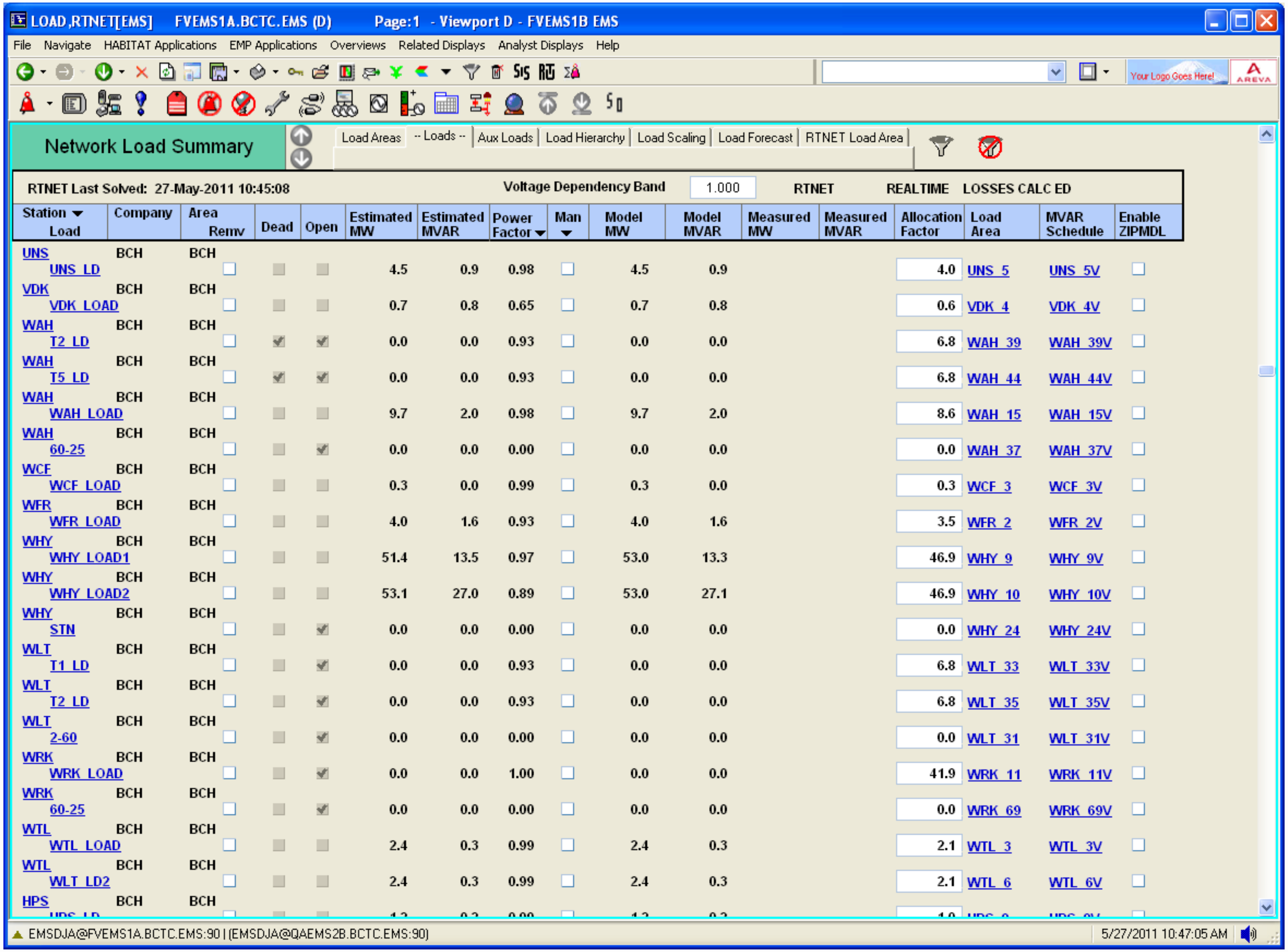


LOAD ALLOCATION METHODOLOGY

BC hydro



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Network Load Summary

Load Areas | -- Loads -- | Aux Loads | Load Hierarchy | Load Scaling | Load Forecast | RTNET Load Area

RTNET Last Solved: 27-May-2011 10:45:08 Voltage Dependency Band 1.000 RTNET REALTIME LOSSES CALC ED

Station / Load	Company	Area	Remv	Dead	Open	Estimated MW	Estimated MVAR	Power Factor	Man	Model MW	Model MVAR	Measured MW	Measured MVAR	Allocation Factor	Load Area	MVAR Schedule	Enable ZIPMDL
UNS / UNS LD	BCH	BCH				4.5	0.9	0.98		4.5	0.9			4.0	UNS 5	UNS 5V	
VDK / VDK LOAD	BCH	BCH				0.7	0.8	0.65		0.7	0.8			0.6	VDK 4	VDK 4V	
WAH / T2 LD	BCH	BCH		✓	✓	0.0	0.0	0.93		0.0	0.0			6.8	WAH 39	WAH 39V	
WAH / T5 LD	BCH	BCH		✓	✓	0.0	0.0	0.93		0.0	0.0			6.8	WAH 44	WAH 44V	
WAH / WAH LOAD	BCH	BCH				9.7	2.0	0.98		9.7	2.0			8.6	WAH 15	WAH 15V	
WAH / 60-25	BCH	BCH			✓	0.0	0.0	0.00		0.0	0.0			0.0	WAH 37	WAH 37V	
WCF / WCF LOAD	BCH	BCH				0.3	0.0	0.99		0.3	0.0			0.3	WCF 3	WCF 3V	
WFR / WFR LOAD	BCH	BCH				4.0	1.6	0.93		4.0	1.6			3.5	WFR 2	WFR 2V	
WHY / WHY LOAD1	BCH	BCH				51.4	13.5	0.97		53.0	13.3			46.9	WHY 9	WHY 9V	
WHY / WHY LOAD2	BCH	BCH				53.1	27.0	0.89		53.0	27.1			46.9	WHY 10	WHY 10V	
WHY / STN	BCH	BCH			✓	0.0	0.0	0.00		0.0	0.0			0.0	WHY 24	WHY 24V	
WLT / T1 LD	BCH	BCH			✓	0.0	0.0	0.93		0.0	0.0			6.8	WLT 33	WLT 33V	
WLT / T2 LD	BCH	BCH			✓	0.0	0.0	0.93		0.0	0.0			6.8	WLT 35	WLT 35V	
WLT / 2-60	BCH	BCH			✓	0.0	0.0	0.00		0.0	0.0			0.0	WLT 31	WLT 31V	
WRK / WRK LOAD	BCH	BCH			✓	0.0	0.0	1.00		0.0	0.0			41.9	WRK 11	WRK 11V	
WRK / 60-25	BCH	BCH			✓	0.0	0.0	0.00		0.0	0.0			0.0	WRK 69	WRK 69V	
WTL / WTL LOAD	BCH	BCH				2.4	0.3	0.99		2.4	0.3			2.1	WTL 3	WTL 3V	
WTL / WLT LD2	BCH	BCH				2.4	0.3	0.99		2.4	0.3			2.1	WTL 6	WTL 6V	
HPS	BCH	BCH															

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LOAD ALLOCATION METHODOLOGY

LOADAREA,RTNET[EMS] FVEMS1A.BCTC.EMS (D) - Viewport D - FVEMS1B EMS

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Network Load Summary

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Load Area	Parent Area Load	Actual MW	Actual MVAR	Manual	Modeled MW	Base MW	Parent Fraction MW	Schedule	Reactive Scaling Individual	Reactive Scaling Cumulative
WIN_7	SIE	11.0	3.3		12.5	0.0	16.12	WIN_7	1.0000	1.0000
WLM_15	CI	6.7	40.6		3.7	0.0	5.42	WLM_15	1.0000	1.0000
WLM_16	CI	6.1	1.5		3.7	0.0	5.42	WLM_16	1.0000	1.0000
WLT_31	LM	0.0	0.0		0.0	0.0	0.00	WLT_31	1.0000	1.0000
WNR_2	NC	0.5	0.0		0.4	0.0	0.43	WNR_2	1.0000	1.0000
WNK_8	LM	0.0	0.0		0.3	0.0	0.46	WNK_8	1.0000	1.0000
WNK_9	LM	0.0	0.0		0.3	0.0	0.46	WNK_9	1.0000	1.0000
WOS_3	VI	0.0	0.0		2.7	0.0	2.08	WOS_3	1.0000	1.0000
WOL_5	CI	2.8	0.0		1.7	0.0	2.46	WOL_5	1.0000	1.0000
WRK_11	LM	0.0	0.0		31.6	0.0	41.91	WRK_11	1.0000	1.0000
WSN_76	CI	0.0	0.0		0.0	0.0	0.00	WSN_76	1.0000	1.0000
WSN_77	CI	0.0	0.0		0.0	0.0	0.00	WSN_77	1.0000	1.0000
WSSWKP_1	WKPL	35.4	12.9		25.0	0.0	31.57	WSSWKP_1	1.0000	1.0000
WTL_3	LM	2.4	0.3		1.6	0.0	2.09	WTL_3	1.0000	1.0000
WTL_6	LM	2.4	0.3		1.6	0.0	2.09	WTL_6	1.0000	1.0000
WWD_2	SIW	0.8	0.0		0.6	0.0	0.67	WWD_2	1.0000	1.0000
WWL_2	CI	1.9	0.4		1.1	0.0	1.65	WWL_2	1.0000	1.0000
WWL_5	CI	1.9	0.4		1.1	0.0	1.65	WWL_5	1.0000	1.0000
GMS_75	CI	2.3	0.7		1.4	0.0	2.00	GMS_75	1.0000	1.0000
REV_48	SIW	2.3	0.7		1.7	0.0	2.00	REV_48	1.0000	1.0000
POW_7	LM	0.0	0.0		0.0	0.0	0.00	POW_7	1.0000	1.0000
SEV_18	SIE	0.0	0.0		0.0	0.0	0.00	SEV_18	1.0000	1.0000
SLO_6	CI	9.7	6.3		6.7	0.0	9.76	SLO_6	1.0000	1.0000
VIT_111	VI	0.0	0.0		0.0	0.0	0.00	VIT_111	1.0000	1.0000
VIT_112	VI	0.0	0.0		0.0	0.0	0.00	VIT_112	1.0000	1.0000
OFD_16	NC	0.0	-0.0		0.0	0.0	0.00	OFD_16	1.0000	1.0000
OFD_17	NC	0.0	0.0		0.0	0.0	0.00	OFD_17	1.0000	1.0000
HRD_9	LM	45.9	13.4		30.0	0.0	39.78	HRD_9	1.0000	1.0000

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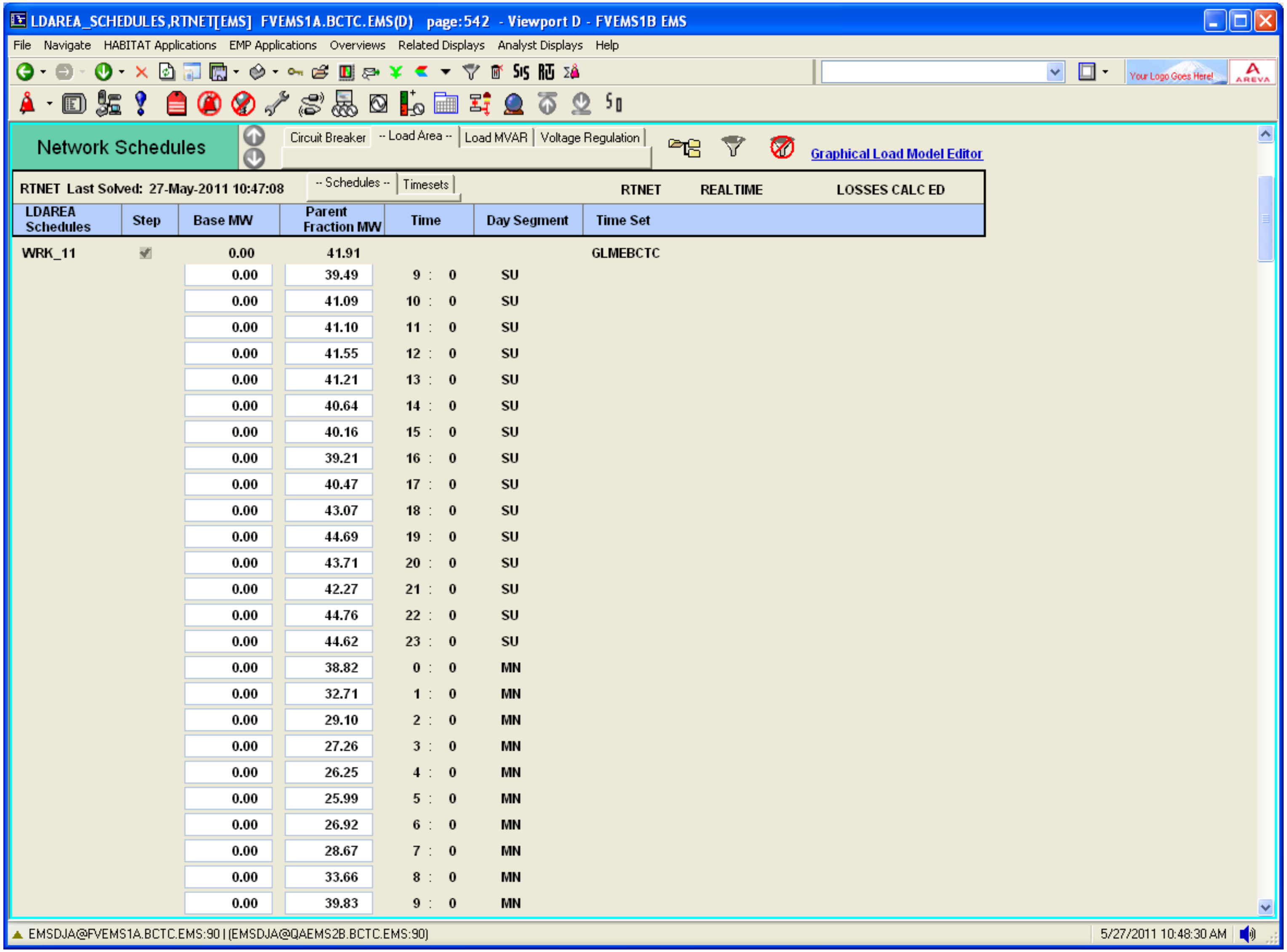
LOAD ALLOCATION METHODOLOGY



LDAREA Schedules	Step	Base MW	Parent Fraction MW	Time	Day Segment	Time Set
WRK_11	✓	0.00	41.91			GLMEBCTC
		0.00	39.49	9 : 0	SU	
		0.00	41.09	10 : 0	SU	
		0.00	41.10	11 : 0	SU	
		0.00	41.55	12 : 0	SU	
		0.00	41.21	13 : 0	SU	
		0.00	40.64	14 : 0	SU	
		0.00	40.16	15 : 0	SU	
		0.00	39.21	16 : 0	SU	
		0.00	40.47	17 : 0	SU	
		0.00	43.07	18 : 0	SU	
		0.00	44.69	19 : 0	SU	
		0.00	43.71	20 : 0	SU	
		0.00	42.27	21 : 0	SU	
		0.00	44.76	22 : 0	SU	
		0.00	44.62	23 : 0	SU	
		0.00	38.82	0 : 0	MN	
		0.00	32.71	1 : 0	MN	
		0.00	29.10	2 : 0	MN	
		0.00	27.26	3 : 0	MN	
		0.00	26.25	4 : 0	MN	
		0.00	25.99	5 : 0	MN	
		0.00	26.92	6 : 0	MN	
		0.00	28.67	7 : 0	MN	
		0.00	33.66	8 : 0	MN	
		0.00	39.83	9 : 0	MN	

LOAD ALLOCATION METHODOLOGY

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- The calculation of load allocation factors is based on the following inputs:
  - Real-time data (MW, MVAR, Amps and KV) archived in PI
  - Load curves for each load that are based on historical information collected from billing department or from real-time (PI)
  - Grouping of loads and measurements into network pockets
- Filtering and smoothing techniques are used to process the input data, eliminate and substitute for bad data and determine the value of MW allocation factor and power factor for each load at a given hour

LOAD ALLOCATION METHODOLOGY

BC hydro

- The calculation algorithm based on the concept of network pockets
- The entire BC Hydro network is broken into network pockets (super buses) that group loads and adjacent real-time measurements
- The grouping is performed to create the smallest network pockets that can be observed by valid real-time measurements
- Ideally, the smallest network pocket would consist of a single load with direct MW and MVAR measurements

LOAD ALLOCATION METHODOLOGY

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- Network pockets are defined manually through in depth analysis. Friendly user interface is provided for network pocket definition
- The analysis would start with locating the loads and determining the closest MW and MVAR measurement pairs that can observe the loads
- In the absence of MW/MVAr measurement pairs the KV and Amps measurements located at the same spot could also be used to observe a network pocket
- An approximate but sufficiently accurate approach is used to convert KV and Amps measurements into the equivalent MW/MVAR pairs

LOAD ALLOCATION METHODOLOGY

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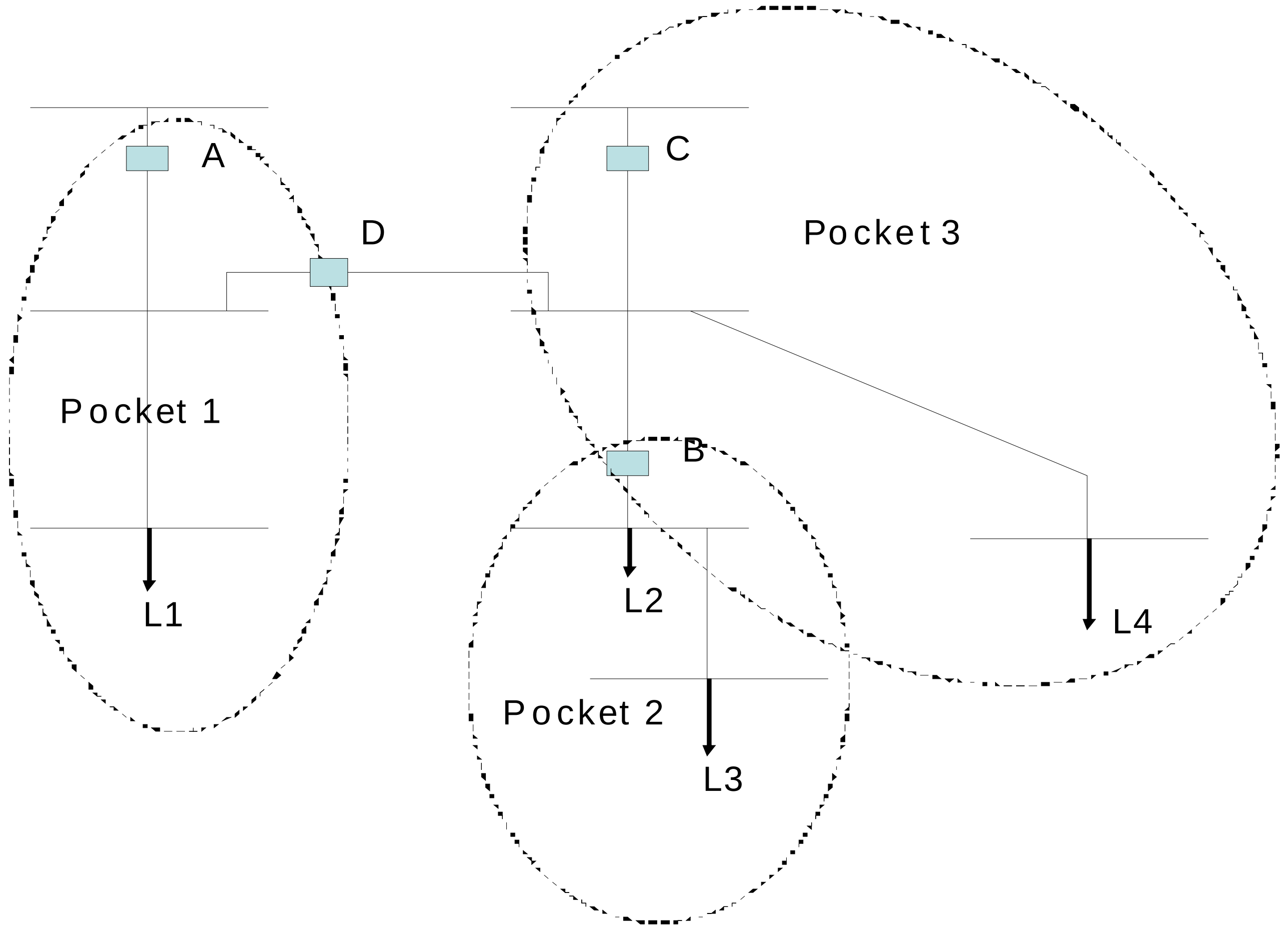

LOAD ALLOCATION METHODOLOGY

BC hydro

- Archived values of real-time measurements used to observe network pockets are retrieved from PI
- If archived values are found invalid for the particular day and time interval, the smoothing technique is applied to interpolate the values of adjacent intervals.
- The algebraic sum of a network pocket measurements is calculated. This sum is distributed over loads that are part of the network pocket.
- Distribution is performed using load curves that are determined through a series of filtering processes applied on historical data (LCF) or, when available, direct real-time data (PI) archived for each load

IMPACT ON STATE ESTIMATOR SOLUTION QUALITY

BC hydro

- Improves the quality of pseudo measurements (loads)
- Improves the quality of real-time load model
- Improves the quality of pre-SE power flow solution
- Significantly improves quality of load allocation (load allocation error quality index was reduced by 30%)
- Improves the total cost function
- Sets stage for better tuning – further reduction of bus mismatches (MW, MVAR)

IMPACT ON STATE ESTIMATOR SOLUTION QUALITY

- Load allocation error improved by 30%
- Cost function improved by 10%
- Total bus MW mismatch improved by 10%
- Pre-SE power flow robustness improved by 4% (convergence rate went up from 93% to 97%)

BRANCH PSEUDO MEASUREMENTS

BC hydro

- MW and MVAR flow measurements can be placed in branches (lines, transformers)
- Power flow calculated by pre-SE provides values for pseudo MW and MVAR
- Used to enforce branch flows in lines adjacent to generator buses
- Increases solution robustness

CONCLUSIONS

- More accurate load allocation improves significantly the quality of pseudo measurements
- Improves state estimator solution quality indices
- Sets stage for better state estimator tuning aimed at further reduction of bus mismatches
- Increases robustness of state estimator and related pre and post-SE power flows
- Has positive impact on other advanced applications such as real-time voltage stability analysis
- Requires regular maintenance process

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QUESTIONS ?

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