Enhancing the System Resiliency using PMU based RAS Scheme

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Tushar, V. Vignesh, P. Banerjee, A. Srivastava
The School of Electrical Engineering and Computer Science,
Washington State University

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Introduction

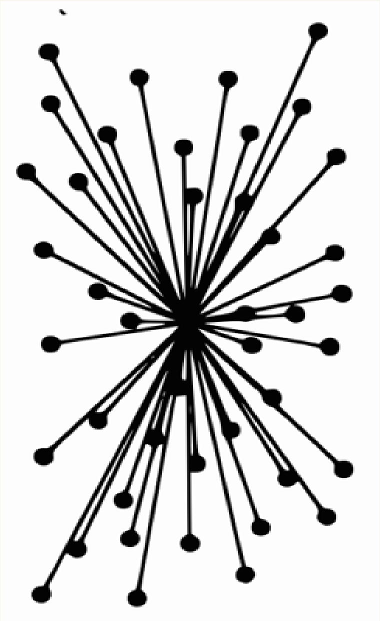
- In order to minimize the wind power curtailment and protect the transmission lines from overload or stability problems, RAS can be deployed for faster control actions.
- Existing RAS are hard coded based on pre-determined control actions. These are non-optimal and controls are designed for local level but may not be good at system level.
- A new dynamic and adaptive RAS is needed using measurements and system status to make control actions.
- New fault-tolerant computational approach needs to be developed to provide fast and correct data to dynamic and adaptive RAS

Classification of RAS –Based on architecture

Centralized

- Not resilient to node failures

- Not scalable

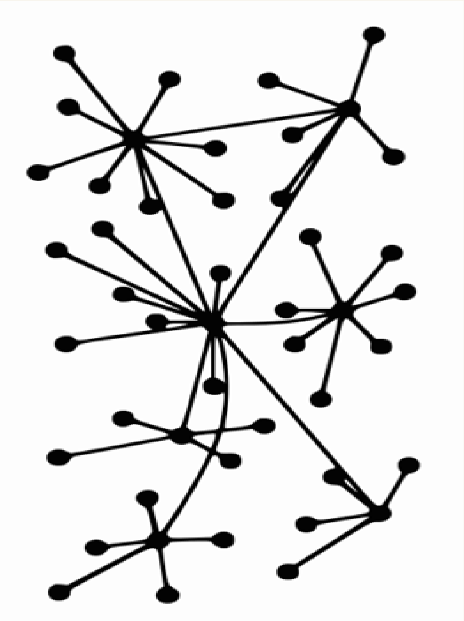


De-centralized

- Resilient to single node failure

- Requires communication among nodes

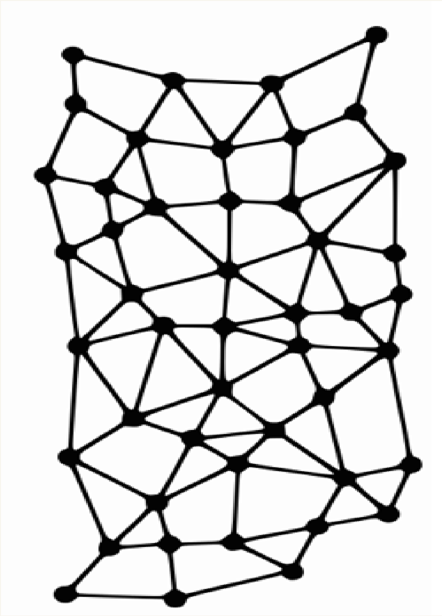
- Data exchange is crucial



Distributed

- Similar to de-centralized

- More complex



Classification of RAS –Based on data

Hardcoded	Adaptive
- Model based	- Measurement based
- Not suitable for changing operating conditions	- Adapts to changes in system parameters and configuration
- May not be fast	- Fast
- Non scalable	- Depends on high resolution measurement data
- Threshold based	- Scalable

More Classification

- Event based
- Response based
- Measurement based
- Precalculated

Formulation of Wind Curtailment RAS

- RAS is developed as a linear programming based optimization of DC power flow

$$P_{Gen} - P_{Load} = B * \theta$$

$$\theta = B^{-1}(P_{Gen} - P_{Load})$$

$$P_{ij} = B_{ij}(\theta_i - \theta_j) \le LR_{ij}$$

Maximize wind connected to the grid but with no overload and no voltage violation

- Objective function

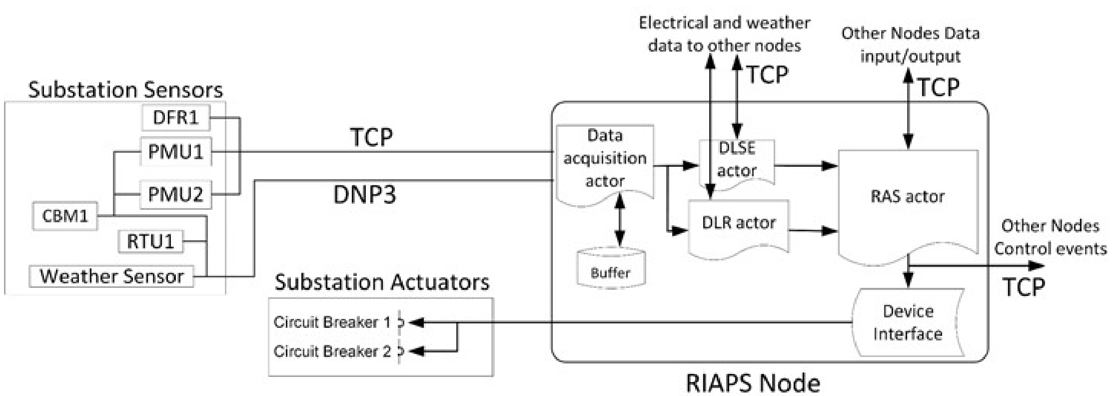
$$Max\, f(x) = \sum_{i=1}^{N_G} x_i * P_{G\_i}$$

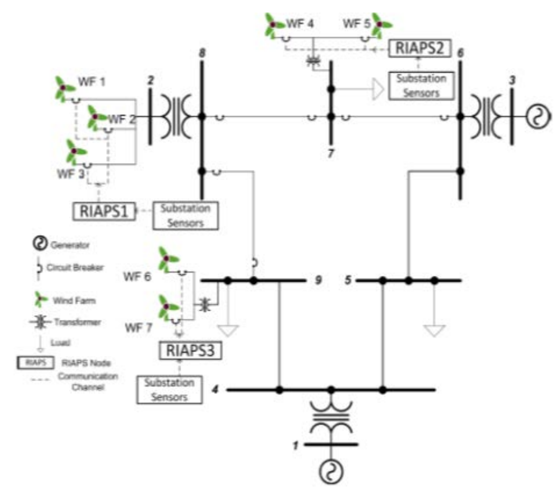
Subject to line constraints

Specifications and Functions for Wind Curtailment RAS

Key modules in Wind curtailment RAS are:

Data Acquisition	Protocol conversion, periodic data input, event data input, time stamping, buffer input data, time aligning
DLSE	Noise filtering, bad data, topology processing
RAS	Initialization, get state variables, optimization, solution update, generate control actions
System testing actor	Testing of system under static and dynamic conditions before deployment

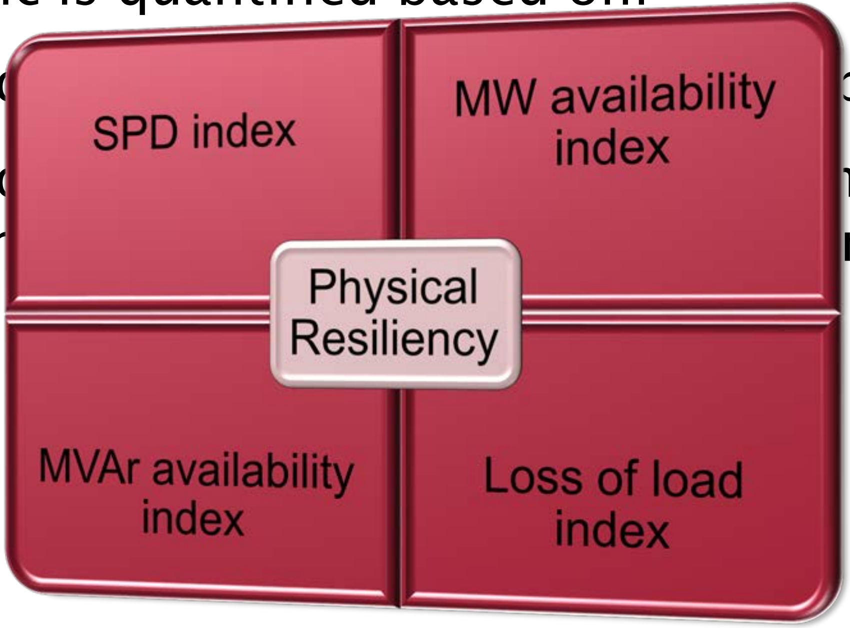




Why resiliency?

- Traditionally, the performance of power system is quantified using reliability indices like SAIDI, SAIFI, etc.
- Extreme events and real-time operating conditions are not considered in the statistics of reliability indices.
- In this study, resiliency of power systems is defined as the ***system's ability to maintain continuous power supply to priority/critical loads (as defined by the user) under disruptive events.***
- Resiliency metric is quantified based on:

1. Network base[...]proach)
2. Electrical fact[...]me measurements to assess the cur[...]m)



Source-Path-Destination (SPD) index

- This index takes into account the **network configuration** and **redundancy in connectivity** along with the physical-based electric flow properties (resistance offered to electric flow).

$$\text{SPD index} = \sum_{i=1}^{N_G} \frac{k_i^2}{\text{BVI}_i * \text{HI}_i * (1 + \text{Average cost}_i)}$$

Branch Vulnerability Index

- It is the measure of number times a branch appears in 'k' source-destination paths.

$$\text{BVI}_i = \sum_{N_L} \frac{n_k}{k}$$

Hops Index

- It is the measure of number of hops (transmission lines, transformers, etc.) linking 'k' source-destination paths.

$$\text{HI}_i = \frac{\sum n_{lk}}{k}$$

Electrical based indices

- The existence of a connection between source (generator) and destination (substation) doesn't always imply that power can be transferred. Thus, electrical factors need to included while computing the resiliency metric for power systems.

- Three factors that are included are:
  - MW availability index
  - MVAr availability index
  - Loss of load index

- MW availability index is the measure of availability of MW power from different generation sources.

$$\text{MW availability index} = \sum_{i=1}^{N_G} \frac{\text{MW availability}_i * \text{Generator Availability}_i}{\text{MW critical/priority load}}$$

- MVAr availability index is the measure of availability of MVAr power to sustain voltages at distribution level.

$$\text{MVAr availability index} = \sum_{N_{RR}} \frac{\text{MVAr availability}}{\text{MVAr priority/critical load}}$$

Electrical based indices

- Loss of Load Index is the measure of total amount of critical/priority load being supplied by the system.

$$\text{Loss of load index} = \frac{\text{Actual priority load supplied}}{\text{Total priority load}}$$

Resiliency metric

- All the above indices are combined together using **Analytical Hierarchical Process** into a single resiliency metric.
- The weights are the **eigenvector** of the combination matrix that is defined by the user indicating the co-relation between different indices.

Enabling resiliency in transmission systems

- Redundancy (standby, backup, spare)
- Maintenance (corrective, preventive, etc.)
- Different architectural implementation

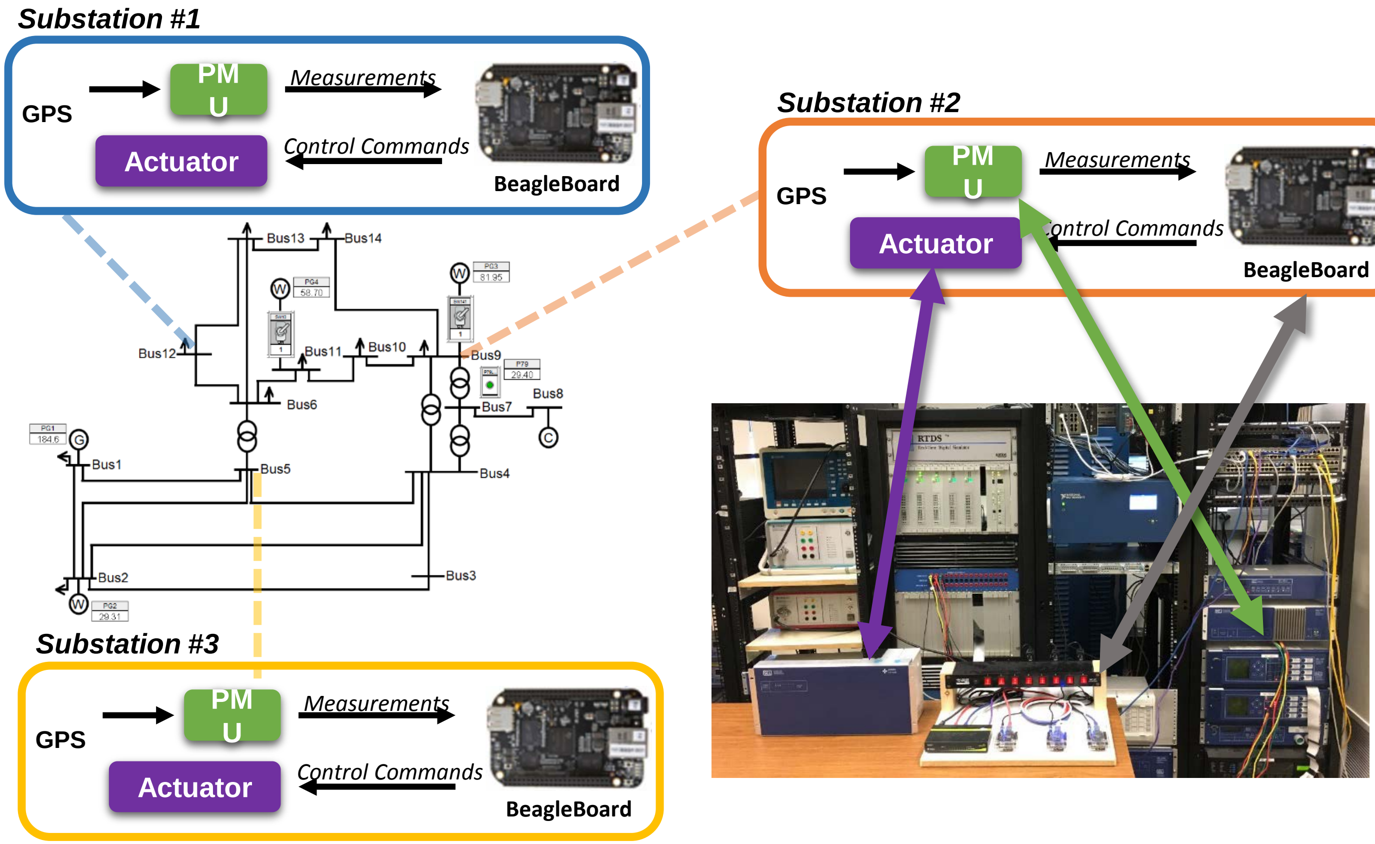
→ More resilient but less cost effective

- Prognostic health management
- Automation of substations
- Wide-area automated protection schemes

→ Use of incoming data

Control actions based on present condition

Cyber-physical RAS simulations test bed



IEEE 14 bus system – Bus 10

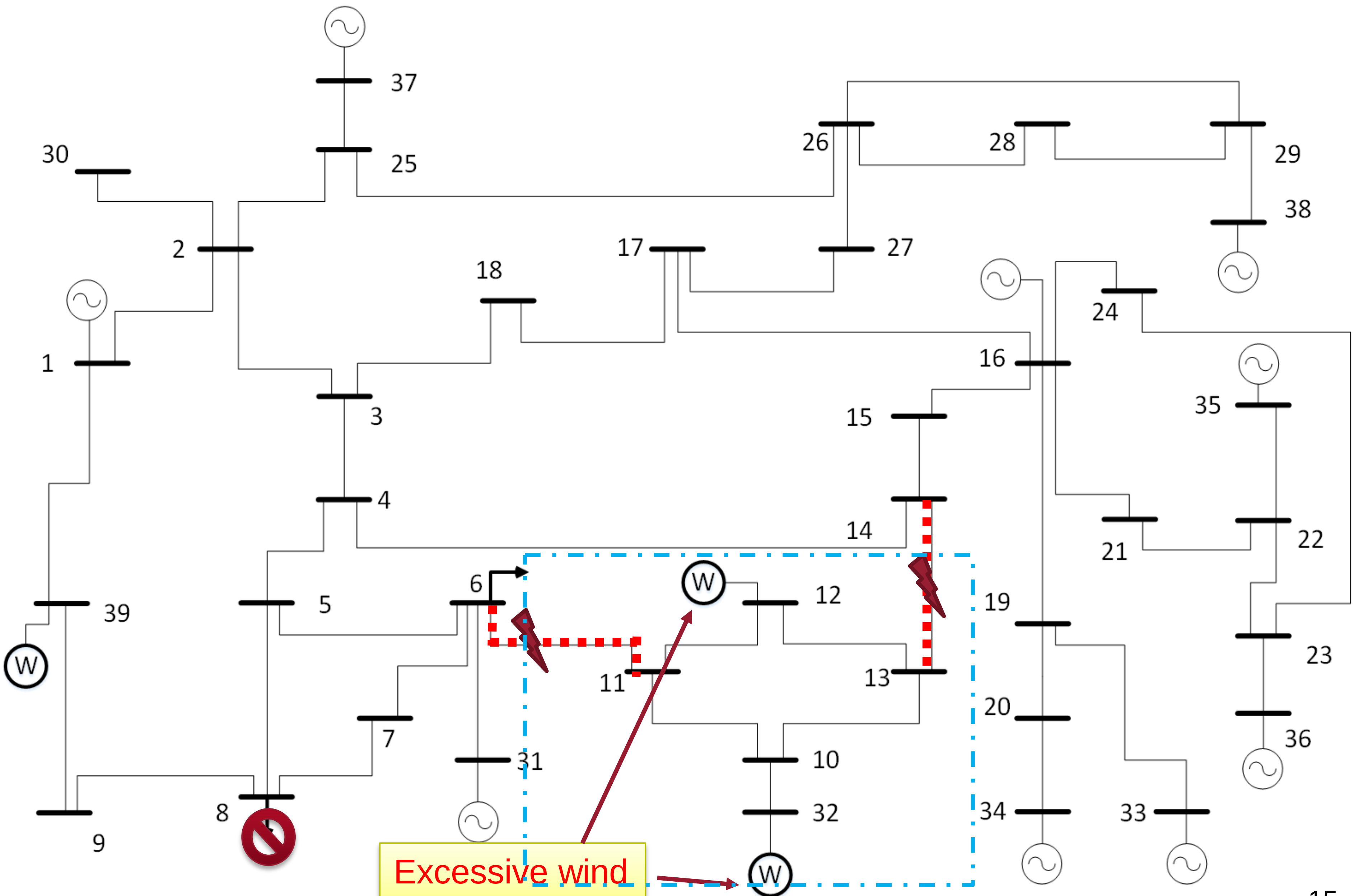
Bus 10	SPD index	MW availability index	MVAr availability index	Loss of load index	Resiliency
Base case	23.315	37.908	68.830	1	1.000
Excess wind generation (without RAS)	7.539	39.375	63.097	1	0.851
Excess wind generation (with RAS)	23.315	39.173	68.780	1	1.002

Performance of RAS during a cyber attack

Normal condition	Wind Gen-1	Wind Gen-2	Wind Gen-3
MW generation data input during excessive wind generation (MW)	37.52	97.78	71.72
MW generation with centralized and de-centralized RAS under normal operation	11.75	24.22	67.64

Cyber attack (False data injection)	Wind Gen-1	Wind Gen-2	Wind Gen-3
MW generation data input to RAS during excessive wind generation (MW)	37.52	**60**	71.72
MW generation with centralized RAS under normal operation	FAILED		
MW generation with distributed and RAS under normal operation	18.32	20.97	16.14

Modified IEEE 39 bus system



IEEE 39 bus system

Bus 6	SPD index	MW availability index	MVAr availability index	Loss of load index	Resiliency
Base case	43.179	59.49	94.065	1	1.000
Excess wind generation (without RAS)	17.881	51.461	103.375	1	0.863
Excess wind generation (with RAS)	43.179	60.422	101.669	1	1.004
Bus 8	**SPD index**	**MW availability index**	**MVAr availability index**	**Loss of load index**	**Resiliency**
Base case	47.728	9.518	12.542	1	1.000
Excess wind generation (without RAS)	12.5113	8.234	13.783	0.806	0.703
Excess wind generation (with RAS)	47.728	9.668	13.556	1	1.004

Acknowledgement

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Thank You

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