U.S. DEPARTMENT OF ENERGY
Office of Electricity

Novel Concept for Flexible and Resilient Large Power Transformers

TRAC Program Review

US Department of Energy, Office of Electricity

Presented at Oak Ridge National Laboratory

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ABB

Award: Details and Deliverables

Award # DE-OE0000854

- 1-year project; Budget: $445,380; DOE Share: $356,304
- Execution period: January 2017 to December 2017
- Project Team:

  ABB - US CRC and PGTR NAM TC

  V.R. Ramanan (PM), Parag Upadhyay (PI)

  Transformer component design, optimization, and integration; benefit quantifications

  UTK – Yilu Liu

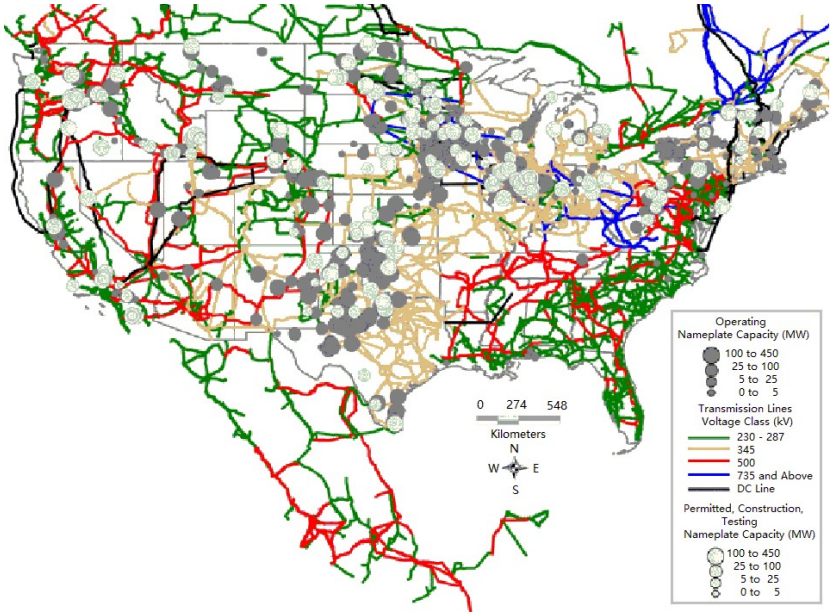
  Design specification optimization and system requirement specification

- System Requirement Specifications
- Design Requirements from System Consideration
- Unit Design Evaluations - Process set-up and baseline, Examine design alternatives, Examine construction alternatives
- Modified Customer Value Proposition
- Impact of Variable and Mismatched Impedance
- The project completed in December 2017 and final technical report is delivered

Problem Statement, Objective and Motivation

Problem statement:

- *Transformer as backbone: Natural disasters - need resilient, flexible large power transformers for quick power restorations*
- *Expensive to keep spare: The US Power network has w*ide range of Ratings
- Transportations weight: <42 metric tons (Enables transport on roads)



Objective:

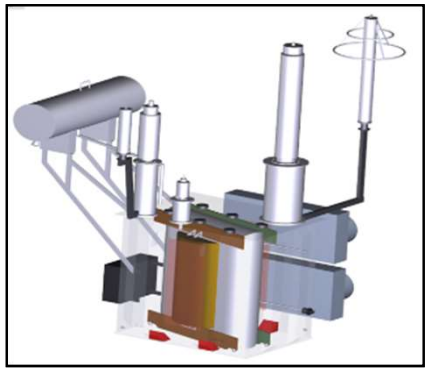
Evaluate feasibility of constructing, installing, and servicing flexible large power transformers comprising easily transportable, standardized building blocks

Motivation:

- Reduce the lead time, black-out times and restoration time, increased grid resiliency
- Building reconfigurable, flexible and easily transportable concept transformer
- Reducing cost of ownership to the customers

State of the Art Approaches for Addressing the Problem

- Efforts are made to keep spare transformers for the resiliency requirements, but the solution is not transportable for large transformer cases.
- The **RecX** solution developed by ABB successfully demonstrated a resilient single phase transformer solution, but the solution is not flexible



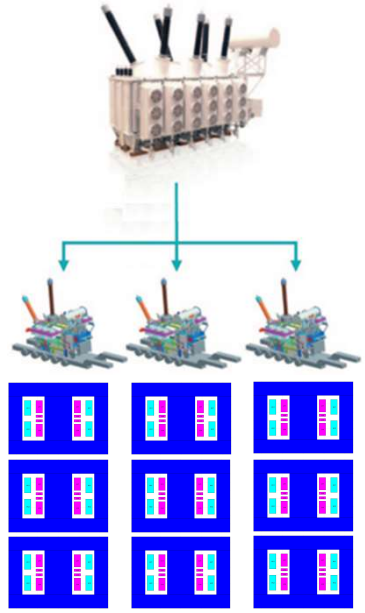
- Beyond this solution, in order to accommodate flexibility of wide range of voltage (69 to 500 kV), and power (100 to 600 MVA), a further modular solution is necessary using the least number of modules possible to make it transportable using the utility trucks (<42 matric tons)

Uniqueness of the Proposed Solution

Proposed Flexible solution has following features;

- Reduced number of designs **(~12)** to accommodate most installed ratings **(500+)** and performance requirements of large power transformers in US power grid
- Transportation weight for all designs **< 42 Tons**
- **Refined customer value proposition**: Incorporation of lead time, downtime, transportation cost, installation cost, design and testing cost, streamlined supply chain, etc., justifies the increased initial cost.

Multiple modules to construct a 3-ph transformer



1-phase module designs

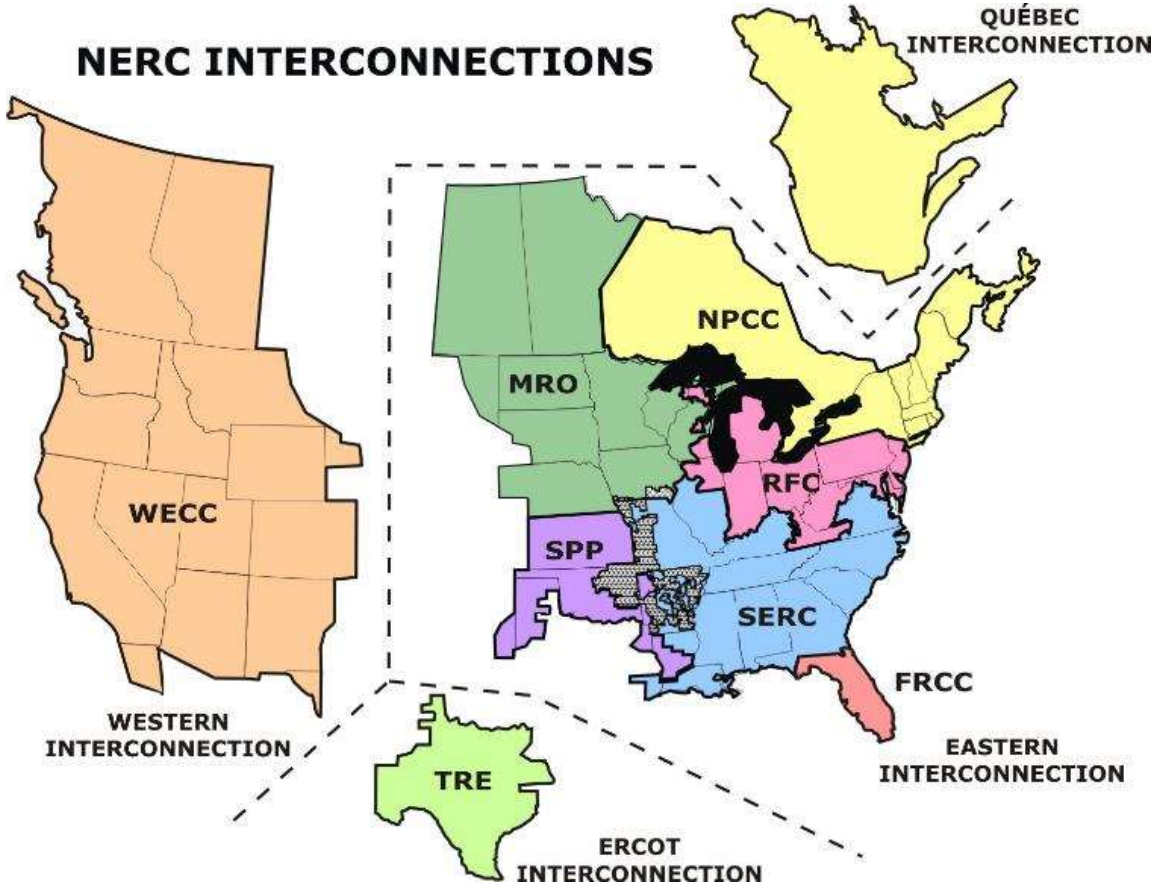
Wide range of power rating accommodated by two winding configurations.

Proposed Technical Approach

- Base Cases of the Power System Analysis - Interconnections of North America
- Project Scope (Derived from FOA and System Analysis)
- Transformer Design specification Summary
- Construction and Design Alternatives
- Short Circuit Impedance for Operating Conditions at Various Power and Voltage Levels
- Transformer Impedance Sensitivity Study – System Level
- Modified Cost of Ownership

Base Cases of the Power System Analysis - Interconnections of North America

- The detailed models from power flow base cases of three interconnections are used in this study.
- The voltage levels of the concerned transformers (High voltage side: 110kV – 500kV)



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Project Scope (Derived from FOA and System Study):

Project Scope:

- Voltage ratings: HV side 69 kV to 500 kV
- Power Ratings: 100 MVA to 600 MVA
- Impedance: 10% to 20% (From power system study)
- Transportable weight: < 42 metric tons

	Low Side							
High Side	345 kV	230 kV	161 kV	138 kV	115 kV	69 kV	35 kV	4 kV
765 kV	9	1	1	14	3	7	1	15
500 kV	3	107	16	43	69	43	3	153
345 kV	-	18	27	269	185	136	10	336
230 kV	-	-	87	226	628	422	56	528
161 kV	-	-	-	44	162	336	14	158
138 kV	-	-	-	-	365	1129	35	476
115 kV	-	-	-	-	-	390	213	337
69 kV	-	-	-	-	-	-	109	264

- Most installed ratings and performance requirements

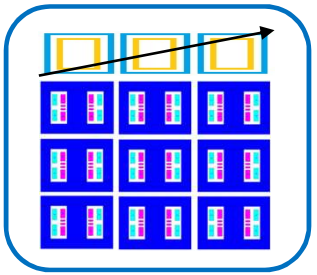
  > 500/230 kV > 345/138 kV > 230/115 kV > 345/115 kV > 230/69 kV

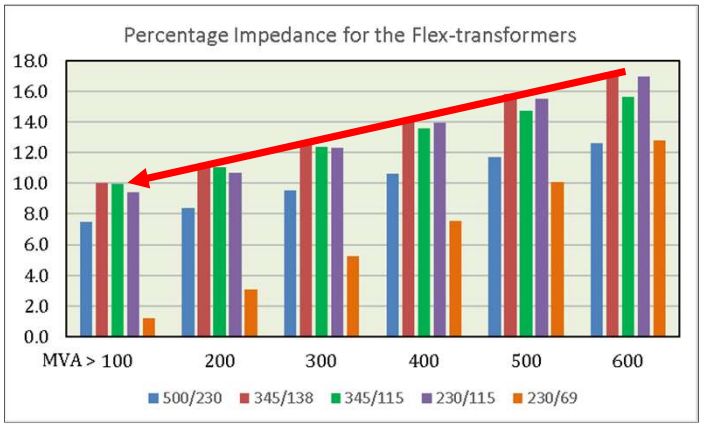
- Justify increased initial cost – by lowering lead time and downtime provides flexibility for restoration and resiliency across the grid
- Reduced number of designs – to streamline supply chain

Results: Short circuit impedance

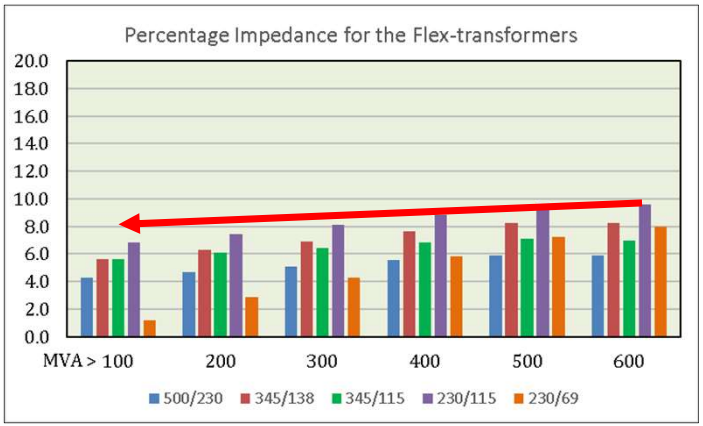
For operating conditions at various power and voltage levels

- It is possible to achieve desired impedances through design change in base 12 designs
- The variation in short circuit impedances for these 12 designs will change overall impedance as shown in following figures.
- All impedances are within 10 to 20% range as modified design
- The base impedance can be achieved for all ratings, and desired additional impedance is provided by external variable impedance.





Initial



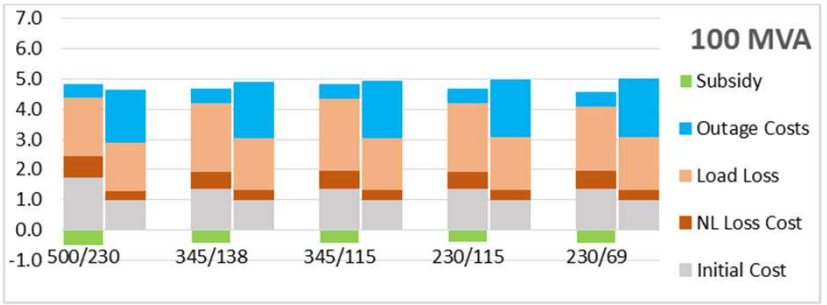
Minimized

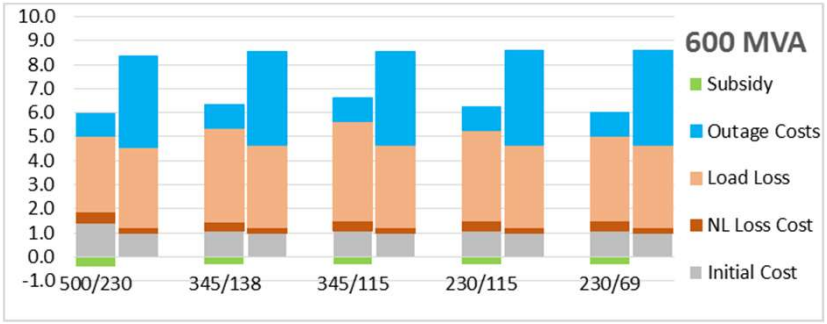
Results: Modified Cost of Ownership (MCOO)

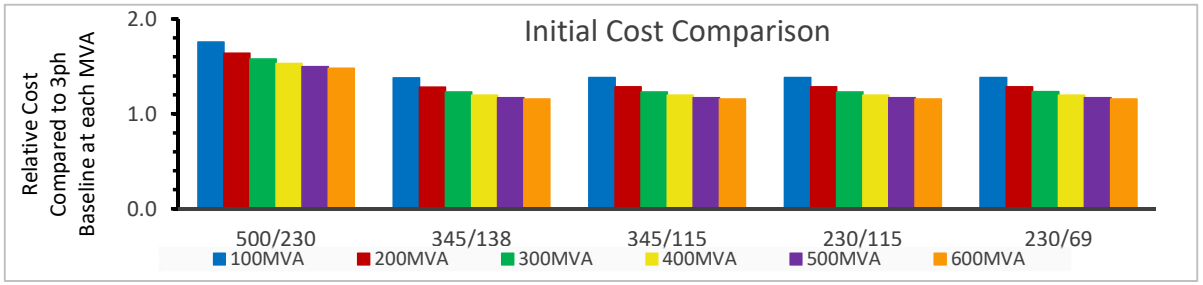
Additional Considerations

Costs of Losses, Downtime, and Value of Service Reliability & Avoided revenue

- Initial cost, No load losses, Load losses
- Downtime from an extended power outage
  - Greater economic impact from outage
  - Comparing 5 vs 20 day outage for Flexible vs Conventional replacements
- Subsidy and Incentives are the promotive factors
- No change in cost or time for maintenance







- MCOO is lower for flexible transformers
- However, found more benefit at higher power ranges

Thank You