OAK RIDGE
National Laboratory

EMT Initiative: Input Data Structures & Models WG

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U.S. DEPARTMENT of ENERGY

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Introduction

Scope:

2025 - Understanding the state-of-art, identifying the gaps and challenges in existing EMT simulation models and in input data structures of simulators, and obtain recommendations from the key stakeholders to derive a timeline-driven roadmap

2026 – (i) Develop standardized input data structure for EMT models; (ii) Develop specifications for creating EMT benchmark models with primary focus on large load integration; (iii) Develop specifications for large load models

Past and Ongoing Activities:

- Met on a weekly basis during April-July ‘25 and now meets bi-weekly
- Multiple speakers already in ’26
- Continues enthusiastic participation from WG members

Future Activities:

- WG2 webinar on April 21 (All invited), SPP talk, white paper on model quality and large load ride-through requirements

Background and State of the art

- **Existing methods** require **customized, ad-hoc extensions for EMT modeling** from base case power flow (e.g., .raw), dynamic (e.g., .dyr), and short circuit (e.g., .seq) analysis

- Common Grid Model Exchange Standard (**CGMES**) Library under Common Information Model (CIM)

- Extension from base case popular in North America: CGMES CIM is not popular

- Real-code EMT models by Joint Working Group of CIGRE B4.82 and IEEE: Dynamic Linked Libraries (DLL) are associated with Windows

Gaps and Challenges

- Lack of Standardized Model Formats
- Vendor Black-Box Models (DLLs)
- Poor Interoperability
- Inconsistent Input Data Quality
- Event/Scenario Management is Manual
- Limited Support for Large Systems
- Documentation & Metadata Deficiency
- Integration with real-world data is Manual
- Validation & verification
- Workforce development

Next UP

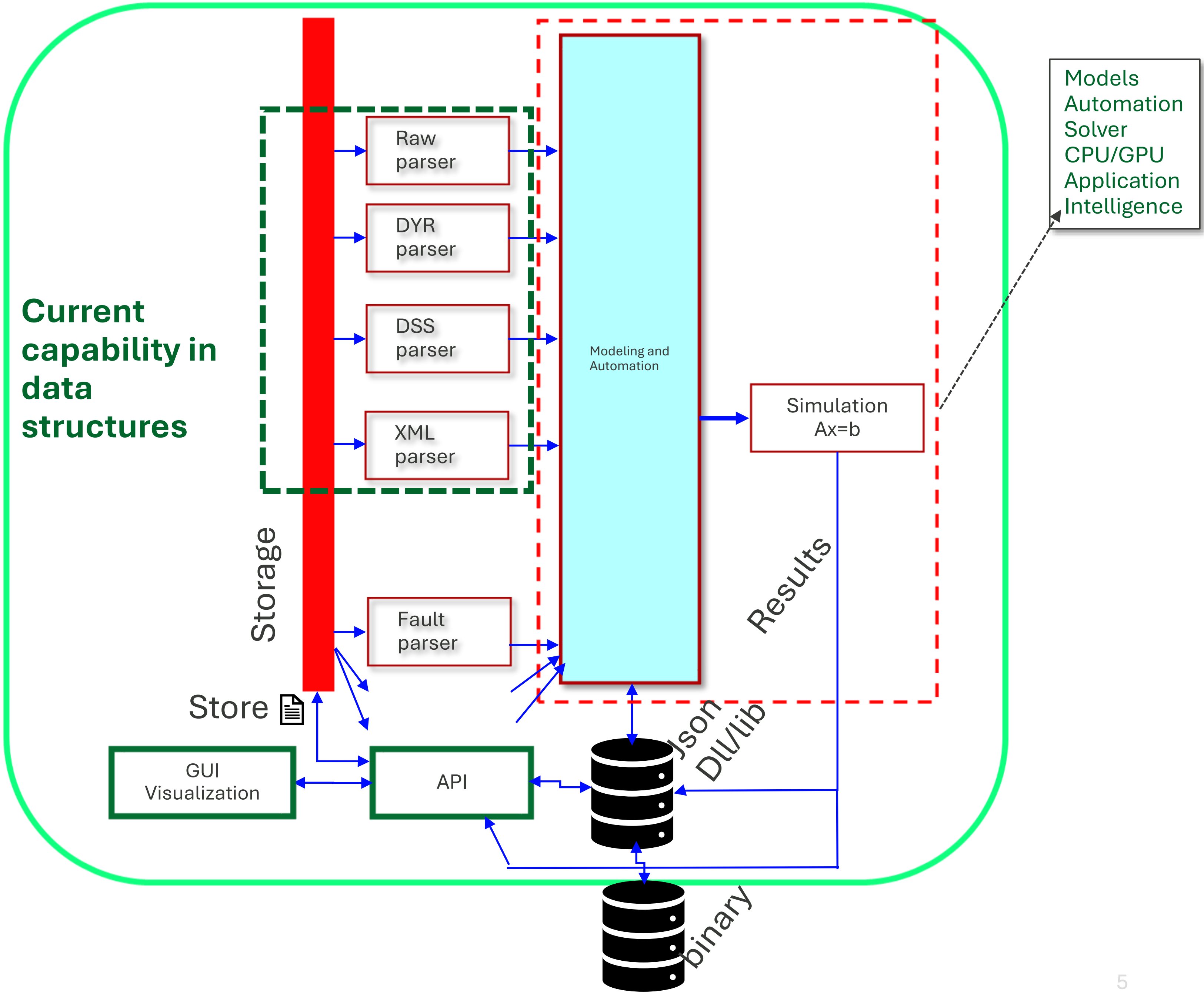
- Short demo of RE-INTEGRATE that uses different data structures, e.g., .raw, .dyr, .dss, and .xml files
- Showcase that it gets challenging to maintain multiple data formats that make it difficult to make the simulation files portable

Standard data format will help with building, updating, validating, and simulating EMT models

RE-INTEGRATE Input Data Structure: Vision

Multiple data formats and sources are needed for high-fidelity EMT simulations.

- Raw: Connectivity, branch, transformer
- Dyr: Generator dynamics
- Dss: Distribution (within generation or load)
- Xml: Power electronics data
- Json: Common data architecture
- Fau: Fault data



PSS/E RAW and DYR Data: Example Missing Data (MTdc)

PSS/E data for Mult-terminal High Voltage Direct Current (MTdc) station for harmonic study

"fields":["name", "acbus", "hstate", "vharm", "iharm"],

name : Multi-terminal dc line
acbus : Bus number
hstate : Current control state
vharm: Voltage source harmonic table
iharm: Current source harmonic table


```
<Station_hardware>
    <name>faultt</name>
    <value>100</value>
    <name>faultclear</name>
    <value>100.1</value>
    <name>start_in</name>
    <value>0</value>
    <name>Rg_ac</name>
    <value>0.001</value>
    <name>Rg_dc</name>
    <value>0.001</value>
    <name>R_pac</name>
    <value>1e9</value>
    <name>R_pdc</name>
    <value>1e9</value>
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```

```
<Station_software>
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    <value>1e9</value>
    <name>Q_ref</name>
    <value>0.5e9</value>
    <name>Udc_ref</name>
    <value>525</value>
    <name>G_droop_ref</name>
    <value>0.2</value>
    <name>Udc_ctrl</name>
    <value>0</value>
</Station_software>
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    <value>0.031</value>
    <name>Ls_H</name>
    <value>0.0387</value>
    <name>Rs_Ohm</name>
    <value>0.1</value>
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    <name>Ro_Ohm</name>
    <value>0.1</value>
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```

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    <value>1000</value>
    <name>Kpi</name>
    <value>4.5</value>
    <name>Kii</name>
    <value>1.9493177</value>
    <name>Kpc</name>
    <value>4.4683</value>
    <name>Kic</name>
    <value>3.225806</value>
    <name>Kpv</name>
    <value>1000.0</value>
    <name>Kpc4</name>
    <value>4.4683</value>
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    <value>3.225806</value>
    <name>Kpll</name>
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    <name>Kpvdc</name>
    <value>0.5014</value>
    <name>Kivdc</name>
    <value>0.0359999</value>
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    <name>Ki_dcv</name>
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    <value>0.05</value>
    <name>vreflim</name>
    <value>1350.0</value>
    <name>vdclim</name>
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    <name>vclim</name>
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    <name>omega_lower</name>
    <value>0.8</value>
    <name>omega_upper</name>
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    <name>vsdnom</name>
    <value>0</value>
</MMC_software>
```


Data needed for MTdc stations

Highlights the need for new data structure for power electronics

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Dss Data: Example Missing Data (Generation/Load with Inverters)

phases=3 bus1=5
kV=0.48
kVA=314
irradiance=1
Pmpp=285
pf=1
%cutin=0.1
%cutout=0.1

Information needed for the OpenDSS simulator to simulate power flow for a power electronic-based component

Information needed EMT simulation for a power electronic-based component


```xml
<DCACConverter>
    <dcac_hardware>
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            <value>0</value>
            <name>to</name>
            <value>1</value>
            <name>Inverter_type</name>
            <value>1</value>
            <name>RatedPower_MVA</name>
            <value>1</value>
            <name>RatedVoltage_kV</name>
            <value>0.48</value>
            <name>BaseFrequency_Hz</name>
            <value>60</value>
            <name>Filter_type</name>
            <value>1</value>
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            <value>0.05</value>
            <name>L1ac_H</name>
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            <name>Cac_F</name>
            <value>2.0e-4</value>
            <name>Rcac_Ohm</name>
            <value>2.0e+4</value>
            <name>R2ac_Ohm</name>
            <value>0.05</value>
            <name>L2ac_H</name>
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            <name>Cdc_F</name>
            <value>4.95e-3</value>
            <name>Rdc_Ohm</name>
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            <value>1</value>
    </dcac_hardware>
    <dcac_software>
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            <value>0</value>
            <name>to</name>
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            <name>Ftri_inv_Hz</name>
            <value>10000</value>
            <name>N_dcac</name>
            <value>100</value>
            <name>Kpt</name>
            <value>950</value>
            <name>Kit</name>
            <value>1900</value>
            <name>vsqint_upper</name>
            <value>0.01</value>
            <name>vsqint_lower</name>
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            <name>omega_lower</name>
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            <value>0.5</value>
            <name>Ti</name>
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            <name>Maxout</name>
            <value>0.49</value>
            <name>Minout</name>
            <value>-0.49</value>
            <name>idint_UL</name>
            <value>5</value>
            <name>idint_LL</name>
            <value>-5</value>
            <name>iqint_UL</name>
            <value>-5</value>
            <name>iqint_LL</name>
            <value>5</value>
            <name>mod_UL</name>
            <value>1.1</value>
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            <name>Pcon_mode</name>
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            <name>vdcint_UL</name>
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            <value>-5</value>
            <name>FF_vdc_kV</name>
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            <name>Ti_Q</name>
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            <name>Qint_UL</name>
            <value>5</value>
            <name>Qint_LL</name>
            <value>-5</value>
            <name>iqmax_kA</name>
            <value>0.5</value>
            <name>iqmin_kA</name>
            <value>-0.5</value>
    </dcac_software>
    <PV_source>
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            <value>1.3824</value>
            <name>voc</name>
            <value>1.0129</value>
            <name>vmp</name>
            <value>0.7962</value>
            <name>imp</name>
            <value>1.3003</value>
            <name>i3</name>
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            <name>i4</name>
            <value>0.8906</value>
            <name>v3</name>
            <value>0.50645</value>
            <name>v4</name>
            <value>0.90455</value>
    </PV_source>
    <ac_grid_source>
            <name>Rg_ac</name>
            <value>1e-3</value>
            <name>R_pac</name>
            <value>0.5e6</value>
            <name>Vsmag</name>
            <value>480</value>
            <name>omega</name>
            <value>376.991184</value>
    </ac_grid_source>
</DCACConverter>
```


Conclusion: The information and parameters used in traditional power-flow or phase-domain tools are insufficient for high-fidelity EMT simulations.

Highlights the need for new data structure for power electronics

New Design: XML Designs for Power Electronics-Based Components


```xml
<DCAC xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <DCACConverterGroup>
        <DCACConverter>
            <dcac_hardware>
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                <name>to</name>
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                <name>Inverter_type</name>
                <value>1</value>
                <name>RatedPower_MVA</name>
                <value>1</value>
                <name>RatedVoltage_kV</name>
                <value>0.48</value>
                <name>BaseFrequency_Hz</name>
                ...
                <name>R2ac_Ohm</name>
                <value>0.05</value>
                <name>L2ac_H</name>
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                <name>Cdc_F</name>
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                <name>Rdc_Ohm</name>
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                <name>IntegrationMethod</name>
                <value>1</value>
            </dcac_hardware>
            <dcac_software>
                <name>from</name>
                <value>0</value>
                <name>to</name>
                <value>1</value>
                <name>Ftri_inv_Hz</name>
                <value>10000</value>
                <name>N_dcac</name>
                <value>100</value>
                <name>Kpt</name>
                <value>950</value>
                <name>Kit</name>
                ...
                <value>0</value>
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                <value>2</value>
                <name>Idmin_kA</name>
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                <name>Kp_Q</name>
                <value>0.3</value>
                <name>Ti_Q</name>
                <value>0.02</value>
                <name>Qint_UL</name>
                <value>5</value>
                <name>Qint_LL</name>
                <value>-5</value>
                <name>iqmax_kA</name>
                <value>0.5</value>
                <name>iqmin_kA</name>
                <value>-0.5</value>
            </dcac_software>
        </DCACConverter>
    </DCACConverterGroup>
</DCAC>
```


Two Level Converter XML File


```xml
<DCACNPC xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <DCACNPCConverterGroup>
        <DCACNPCConverter>
            <NPC_hardware>
                <name>from</name>
                <value>0</value>
                <name>to</name>
                <value>1</value>
                <name>Inverter_type</name>
                <value>2</value>
                <name>RatedPower_MVA</name>
                <value>1</value>
                <name>RatedVoltage_kV</name>
                <value>0.48</value>
                <name>BaseFrequency_Hz</name>
                ...
                <value>1.25e-4</value>
                <name>Cdc1_F</name>
                <value>1.0e-3</value>
                <name>Cdc2_F</name>
                <value>1.0e-3</value>
                <name>Rdc_Ohm</name>
                <value>2.0e+4</value>
                <name>RPG_Ohm</name>
                <value>1.0e+6</value>
                <name>RccG_Ohm</name>
                <value>1.0e+9</value>
            </NPC_hardware>
            <NPC_software>
                <name>from</name>
                <value>0</value>
                <name>to</name>
                <value>1</value>
                <name>Ftri_inv_Hz</name>
                <value>10000</value>
                <name>N_dcac</name>
                <value>100</value>
                <name>L1ac_H</name>
                <value>1.0e-3</value>
                <name>Kpt</name>
                <value>950</value>
                <name>Kit</name>
                ...
                <value>-4.3</value>
                <name>Idmax_kA</name>
                <value>2</value>
                <name>Idmin_kA</name>
                <value>-2</value>
                <name>QRef_MVA</name>
                <value>0</value>
                <name>Kp_Q</name>
                <value>0.15</value>
                <name>Ti_Q</name>
                <value>0.08</value>
                <name>Qint_UL</name>
                <value>5</value>
                <name>Qint_LL</name>
                <value>-5</value>
                <name>iqmax_kA</name>
                <value>1</value>
                <name>iqmin_kA</name>
                <value>-1</value>
            </NPC_software>
        </DCACNPCConverter>
    </DCACNPCConverterGroup>
</DCACNPC>
```


Neutral Point Clamped Converter XML File


```xml
<MTdc>
   <StationGroup>
     <Station>
         <name></name>
         <value></value>
          ...
         <Transformer>
            <name></name>
            <value></value>
             ...
         </Transformer>
          ...
         <MMC_hardware>
            <name></name>
            <value></value>
             ...
         </MMC_hardware>
         <MMC_software>
            <name></name>
            <value></value>
             ...
         </MMC_software>
       ...
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            <name></name>
            <value></value>
             ...
         <Station_hardware>
     </Station>
      ...
   </StationGroup>
   <ac_sourceGroup>
     <ac_source>
         <name></name>
         <value></value>
          ...
     </ac_source>
      ...
   </ac_sourceGroup>
   <dc_lineGroup>
     <pi_line>
         <name></name>
         <value></value>
             ...
     </pi_line>
    ...
   </dc_lineGroup>
</MTDC>
```
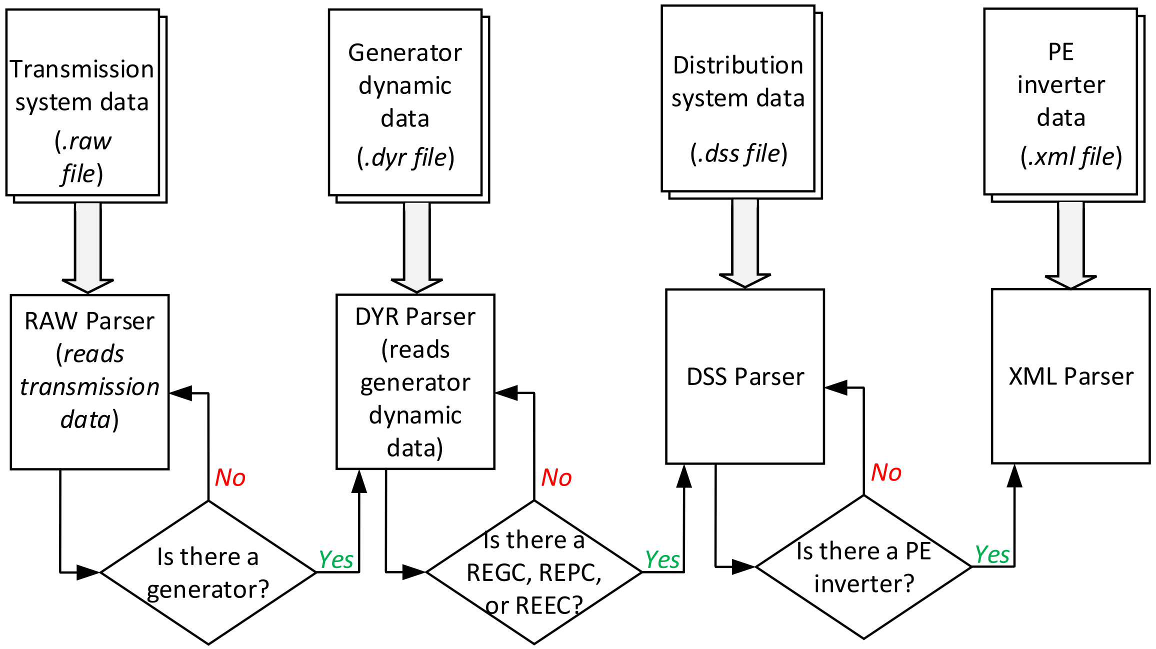


MTdc XML File

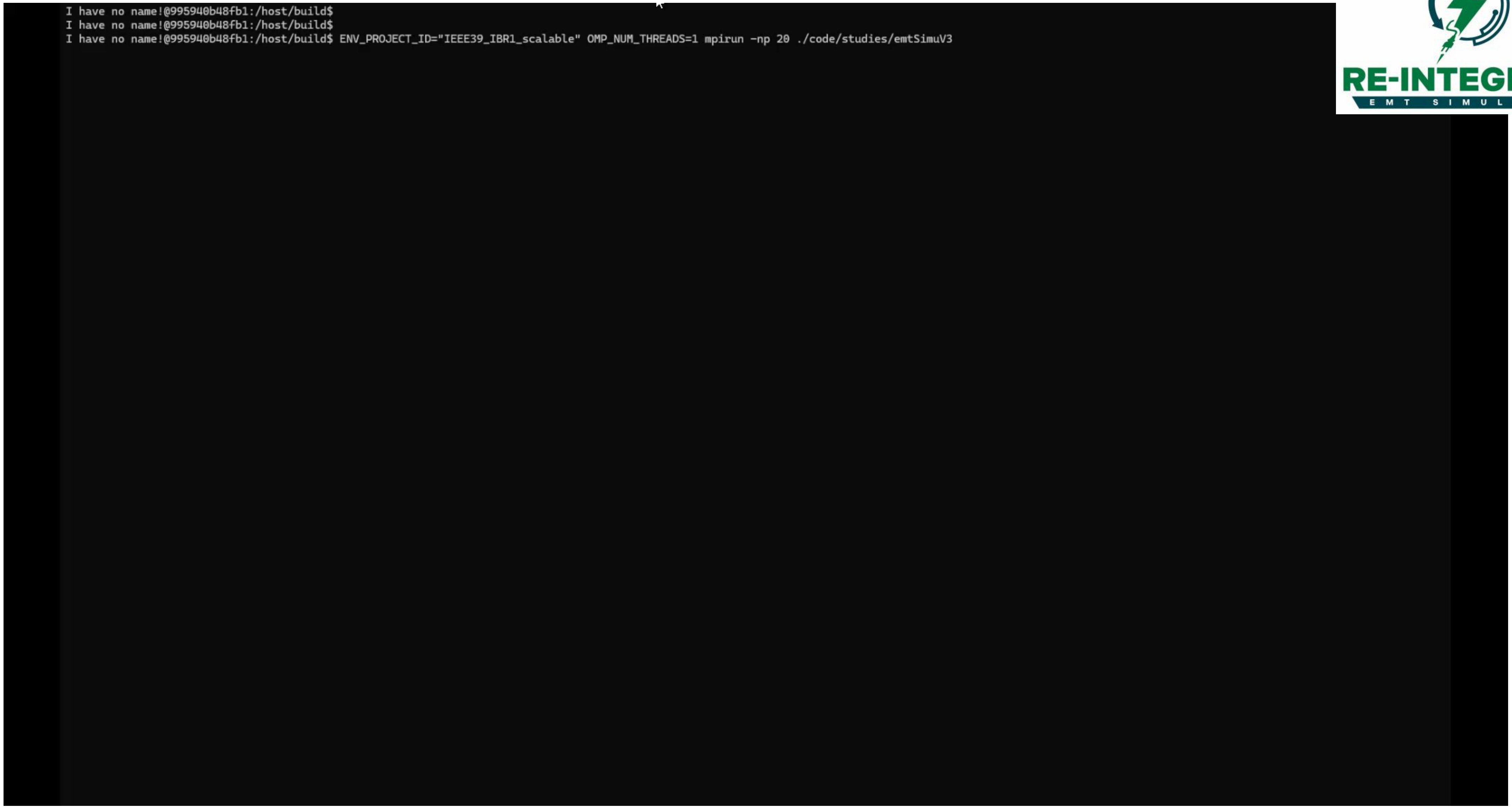
Overall Input Data Structure Workflow

- The process begins with the parser parsing the RAW file. If the RAW parser detects any generator, it triggers the DYR parser to extract dynamic information about the generator from the DYR file.
- The DYR parser analyzes the DYR file and, upon identifying keywords such as REGC, REPC, or REEC (indicating the presence of PE-based generation), it directs the DSS parser to retrieve additional data from the DSS file.
- In the DSS file, if an PE based generation (inverter) is detected, the DSS parser directs XML parser to retrieve additional data related to the inverter from the XML file.



RE-INTEGRATE EMT Simulation: Demo

IEEE 3900-bus with 12,500 inverters



RE-INTEGRATE EMT SIMULATOR

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Thank you

Acknowledgement: Thanks to the Office of Electricity's (OE) Advanced Grid Modeling Program for the support.