Icepak High-Performance Computing at Rockwell Automation: Benefits and Benchmarks

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Outline

• Introduction to Rockwell Automation

• Need for High-Performance Computing with Icepak

• High-Performance Computer Specifications

• Overview of Benchmark Problems

• Benchmark Metrics

• Benchmark Results: Small Blower

• Benchmark Results: Scalable Motor Drive

• Icepak High-Performance Computing Configuration and Use at Rockwell Automation

• High-Performance Computing Benefits

• Conclusions
Rockwell Automation At A Glance

- Fiscal 2010 Sales: Approximately $4.9 billion
- Employees: About 19,000
- Serving customers in 80+ countries
  - emerging markets over 20% of total sales
- World Headquarters: Milwaukee, Wisconsin, USA
- Trading Symbol: ROK

Leading global provider of industrial power, control and information solutions
Need for High-Performance Computing

- Customer demands for higher current outputs and smaller footprints presents a challenge for the thermal management of cabinet-size, scalable motor drives.
- Highly detailed component models are required to predict the temperatures that are used to establish motor drive rating and reliability.

As model sizes scale, Icepak models must be defeatured to stay within computing hardware capabilities.

- As model scales:
  - Information can be lost.
  - Confidence in model can decrease.

- Engineers are unable to model multi-cabinet motor drives due to computer resource limits.

Challenge: Micro-level Detail at Macro-level Scale and Beyond
High-Performance Computing Systems

- Three computers are used for benchmarking.
- Benchmarking results established guidelines for Icepak HPC simulations at Rockwell Automation.

<table>
<thead>
<tr>
<th>Location</th>
<th>Manufacturer/Model</th>
<th>Microprocessor</th>
<th>Clock Speed</th>
<th>RAM</th>
<th>Operating System</th>
<th>Hyper-threading</th>
<th>Number of Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milwaukee Institute Linux</td>
<td>Dell</td>
<td>Dual Quad-Core Intel X5550</td>
<td>2.66 GHz</td>
<td>24 GB 1333 MHz</td>
<td>64 bit Linux</td>
<td>On</td>
<td>13</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA Windows Workstation</td>
<td>Dell Precision T7500</td>
<td>Dual Quad-Core Intel X5550</td>
<td>2.66 GHz</td>
<td>48 GB 1333 MHz</td>
<td>64 bit Windows 7</td>
<td>Off</td>
<td>1</td>
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<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>RA Linux Compute Node</td>
<td>Dell PowerEdge R710</td>
<td>Dual Six-Core Intel X5690</td>
<td>3.46 GHz</td>
<td>96 GB 1333 MHz</td>
<td>64 bit Linux</td>
<td>Off</td>
<td>1</td>
</tr>
</tbody>
</table>
Small Benchmark Problem: MRF Blower

- Detailed blower model using Moving Reference Frame (MRF) technique.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements</td>
<td>629,364</td>
</tr>
<tr>
<td>Solution</td>
<td>Flow</td>
</tr>
<tr>
<td>Turbulence Model</td>
<td>Realizable two equation</td>
</tr>
<tr>
<td>Discretization Scheme</td>
<td>All First Order</td>
</tr>
<tr>
<td>Under-Relaxation</td>
<td>Pressure: 0.3</td>
</tr>
<tr>
<td></td>
<td>Momentum: 0.7</td>
</tr>
<tr>
<td></td>
<td>Viscosity: 1.0</td>
</tr>
<tr>
<td></td>
<td>Turbulent KE: 0.5</td>
</tr>
<tr>
<td></td>
<td>Dissipation: 0.5</td>
</tr>
<tr>
<td>Stabilization</td>
<td>Pressure: BCGSTAB</td>
</tr>
<tr>
<td>Precision</td>
<td>Single</td>
</tr>
<tr>
<td>Partitioning Method</td>
<td>Principal Axes</td>
</tr>
<tr>
<td>Icepak Version</td>
<td>13.0.2</td>
</tr>
</tbody>
</table>
Large Benchmark Model: Scalable Motor Drive

- Scalable motor drive with one, two, and three identical modules.
- Air flow interaction between cabinets.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements</td>
<td>6.2, 11.7, 17.1 million</td>
</tr>
<tr>
<td>Solution</td>
<td>Flow</td>
</tr>
<tr>
<td>Turbulence Model</td>
<td>Realizable two equation</td>
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<tr>
<td>Icepak Version</td>
<td>13.0.2</td>
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</table>

Each Motor Drive contains:

- (1) MRF Blower
- (2) Detailed Heat Sinks
- (3) Detailed IGBTs

Plus: Circuit boards, bus bars, resistors, capacitors, etc.
Benchmark Metrics

- **Speed Up:**

  \[ S(N)_{500} = \frac{\text{Elapsed time}^\ast \text{ for 500 iterations using one core}}{\text{Elapsed time}^\ast \text{ for 500 iterations using N cores}} = \frac{t_{1,500 \text{ iterations}}}{t_{N,500 \text{ iterations}}} \]

  \(^\ast\) taken from "elapsed time" value found in `uns_out` file for each solution

- **Amdahl’s Law:**
  - If \( P \) is the percent of a program that can benefit from parallelization and \( N \) is the number of cores, then according to Amdahl’s Law the calculated Speed Up is:

  \[ S(N)_{Amdahl} = \frac{1}{(1-P) + P/N} \]

  - Assuming a theoretical maximum parallelization of \( P = 100\% \), Amdahl’s Law reduces to:

  \[ S(N)_{Amdahl} = N \]
SMALL BENCHMARK PROBLEM:

*MRF BLOWER*
MRF Blower Benchmark

- Elapsed time versus number of parallel cores

- Elapsed Time significantly decreases as number of cores increase – up to 6 cores.
- More than 6 cores has a negligible effect.
- Comparing Linux machines, reduction in Elapsed Time (32% average) scales with CPU speed \([\frac{(3.46-2.66)}{2.66}] = 30\%\).
MRF Blower Benchmark

• Solver Speed Up versus number of parallel cores

- All machines closely follow Amdahl’s Law up to 4 cores.
- RA Windows Workstation tops out at 6 cores.
MRF Blower Benchmark

- Elapsed time versus number of parallel cores

- 16 core Parallel Solution performs 20% faster than 16 core Network Parallel Solution.
- Decrease in Network Parallel Solution with > 32 cores due to communication overhead.
- Solution using 2 HPC Packs (32 cores) reduces solution time by 33% versus 1 HPC Pack (8 cores).
LARGE BENCHMARK PROBLEM:

SCALABLE MOTOR DRIVE
- Elapsed Time at 500 iterations versus number of parallel cores

- Both Dual 4 core 2.66 GHz machines show nearly identical performance from 2 to 6 cores.
- Additional memory on 2.66 GHz CPUs has no effect.
- Comparing Linux machines, reduction in Elapsed Time (24% average) scales with CPU speed \([(3.47-2.66)/2.66] = 30\%\).

- Both Rockwell Automation machines show no or negative performance gains above 6 cores.
Single Motor Drive

- Solver Speed Up versus number of parallel cores

- All machines follow Amdahl’s Law up to 2 cores.
- RA Linux Compute Node starts to deviate from Amdahl’s Law at 3 cores.

Milwaukee Institute Linux [Dual 4 core, 2.66 GHz, 24 GB]
RA Windows Workstation [Dual 4 core, 2.66 GHz, 48 GB]
RA Linux Compute Node [Dual 6 core, 3.47 GHz, 96 GB]
Amdahl’s Law (Theoretical Linear Speed Up)

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• Elapsed time versus number of parallel cores

- Network Parallel Solution performs the fastest (peak at 64 cores).
- Decrease in Network Parallel Solution performance with > 64 cores due to communication overhead.
- Solution using 2 HPC Packs (32 cores) reduces solution time by 59% versus 1 HPC Pack (8 core).
• Elapsed Time at 500 iterations versus number of parallel cores

- Doubling memory on 4 core 2.66 GHz machine with 4 GB shows ~8% better performance from 1 to 4 cores.
- Comparing Linux machines, reduction in Elapsed Time (21% average) almost scales with CPU speed 
  
  \[ \frac{(3.47-2.66)}{2.66} = 30\% \]

- Both Rockwell Automation machines show little or negative performance gains above 6 cores.
Double Motor Drive

• Solver Speed Up versus number of parallel cores

- Milwaukee Institute Linux [Dual 4 core, 2.66 GHz, 24 GB]
- RA Windows Workstation [Dual 4 core, 2.66 GHz, 48 GB]
- RA Linux Compute Node [Dual 6 core, 3.47 GHz, 96 GB]
- Amdahl's Law (Theoretical Linear Speed Up)

- All machines show a higher deviation from Amdahl's Law than Single Motor Drive model.
- RA Linux Compute Node starts to deviate from Amdahl's Law at 2 cores.
Motor Drive Model Scaling

- Elapsed Time at 500 iterations versus number of parallel cores and number of elements

- Unable to run triple model on Windows Workstation.

- Elapsed time linearly increases with number of elements (< 12 million)
- Slope decreases as cores increase from 2 to 6.
HPC Computer Implementation

- Linux Compute Node implementation at Rockwell has been in place since May 2011.

- Moved from dedicated Workstation with Laptop to Shared Computing Node with Laptop model.

Based on our internal cost models for four Icepak users, Laptop with Shared Computing approach saves 43% per user.
HPC Use Rules at Rockwell Automation

- Based on the benchmarks, the optimal number of parallel cores to minimize solution time are:

<table>
<thead>
<tr>
<th>Benchmark Model</th>
<th>Model Size</th>
<th>RA Linux Compute Node</th>
<th>RA Windows Workstation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRF Blower</td>
<td>0.6 million</td>
<td>8 cores</td>
<td>8 cores</td>
</tr>
<tr>
<td>Single Motor Drive</td>
<td>6.2 million</td>
<td>6 cores</td>
<td>6 cores</td>
</tr>
<tr>
<td>Double Motor Drive</td>
<td>11.7 million</td>
<td>6 cores</td>
<td>8 cores</td>
</tr>
</tbody>
</table>

- Using the data above, we have created a rule where the maximum allowable number of cores for any parallel solutions in Icepak is six.

- This allows for better utilization of the Dual Six-Core Linux Compute Node and HPC Packs.
HPC Benefit at Rockwell Automation

- With High Performance Computing and Icepak, there is not need to defeature as model scale increases.
  - No loss of information
  - No loss of confidence in model
  - No compromises
- We can now economically simulate scalable motor drives and push the limits of power density.
Conclusions

- More parallel cores does not equal a faster solution.

- Amdahl’s Law only holds up to two cores (independent of model size).

- As model size increases, deviation from Amdahl’s Law increases.

- Reduction in elapsed time is proportional to increase in CPU speed.

- For large models near 10 million elements, doubling memory for the same CPU reduced solve time by ~8%.

- Elapsed time linearly scales with model size up to 12 million elements.

- A Parallel Solution with 6 to 8 cores is optimal for the Windows Workstation and Linux Compute Nodes used at Rockwell Automation up to 12 million elements.
Acknowledgements

- The authors gratefully acknowledge:

  - **Jonathon Gladieux** and **Jay Bayne** at Milwaukee Institute for providing 8 months of unfettered access on their high performance computing system to perform benchmarks with Icepak.

  - **Mark Jenich** at ANSYS for generously providing Icepak and multiple HPC Pack licenses to Milwaukee Institute.

  - **Richard Lukaszewski** and **Sujeet Chand** at Rockwell Automation for supporting this work.

  - **Jerry Rabe** at Rockwell Automation for setting up and configuring the Linux Compute Node.
MRF Blower Benchmark Metrics

- **Comparison of Solver Speed Up metrics**

  ![Graph - Milwaukee Institute Linux](image1)
  ![Graph - RA Linux Compute Node](image2)
  ![Graph - RA Windows Workstation](image3)

  \[ S(N)_{500} = \frac{\text{Elapsed time for 500 iterations using one core}}{\text{Elapsed time for 500 iterations using N cores}} \]

  - Less than 8% difference between converged and 500 iteration Solver Speed Up metrics.
  - We will use Solver Speed Up at 500 iterations for all Large Benchmark problems.