White Paper

ANSYS Maxwell and SGI® UV™ 3000 Maximizes Electromagnetic Computation Throughput

Electric machines are being used in more and novel applications throughout the world, driven by the need for greater power efficiency in the transportation, aerospace and defense, and industrial automation markets. In the U.S. industrial sector alone, over 40 million electric motors convert electricity into useful work in manufacturing operations. Industry spends over $30 billion (U.S.) annually on electricity to power dedicated electric-motor-driven systems. There is a clear global demand to develop more power-efficient machines, but progress has been hindered due to the large amount of computational resources and time required to simulate an electric machine.

To design and build more energy-efficient electric machines, companies are using ANSYS Maxwell, a low-frequency electromagnetic simulation software package. Transient electromagnetic field simulation allows analysis of dynamic systems with nonlinear materials and permanent magnets under a variety of conditions, employing sinusoidal waveforms and practically any other pulsed waveform excitation. The process requires sequential calculation, over many time steps, of saturation, eddy currents, slotting effects, and rotor movement in time and space. It is a huge computational undertaking to characterize an electric machine of any kind for steady-state operation; it can take days or weeks to complete. This limits the number of design points that engineers can acquire in a reasonable amount of time to make critical design decisions.

ANSYS and SGI have worked together for over 15 years to bring virtual product development (VPD) solutions to our joint customers worldwide. ANSYS recently teamed with SGI to benchmark a new ANSYS Maxwell technology that delivers dramatic improvement in speed for transient electromagnetic field simulations. Simulations that previously required weeks of computation time are now completed in a matter of hours. Several groundbreaking technologies are working in tandem to deliver this unprecedented speed and capacity improvement. The key software technology is a new algorithm within Maxwell that allows engineers to solve time steps simultaneously as opposed to sequentially. On the hardware side, SGI's UV 3000 advanced symmetric multiprocessing (SMP) computer system eliminates the risks of simulation failure and lost time due to insufficient computing memory, and enables users to perform more Maxwell low-frequency electromagnetic simulations in less time.

"ANSYS' new technology to solve transient electromagnetic field simulations combined with SGI's shared memory computing platform demonstrated a 30 times speed improvement over the baseline simulation benchmark. SGI is pleased to work with ANSYS to perform these groundbreaking benchmarks and excited about the results. The power of ANSYS Maxwell's time decomposition method combined with the SGI® UV™ 3000 solution maximizes computational throughput and enhances the engineer's understanding of the effects of various design changes with the highest fidelity for simulations"

Gabriel Broner
VP and GM of HPC, SGI

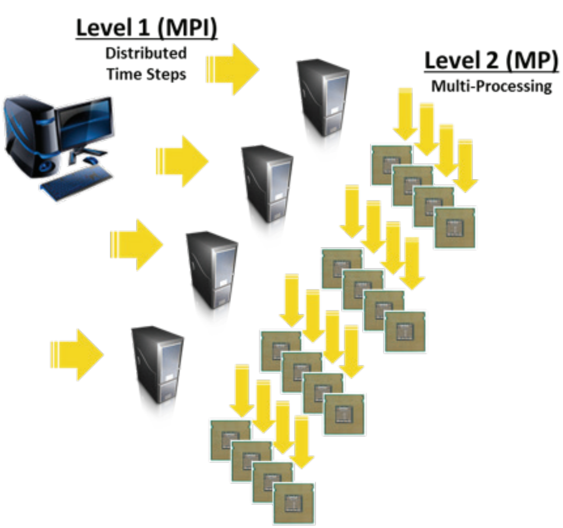


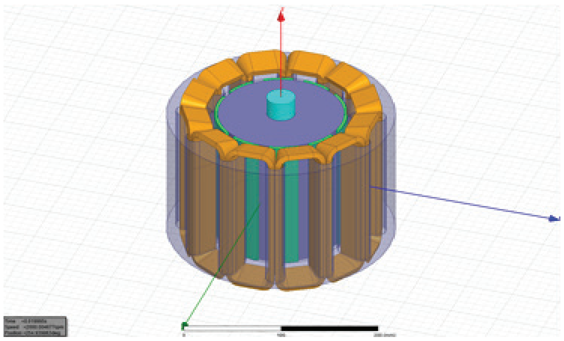
Figure 1. Multi-level HPC for speed and scale

ANSYS Maxwell – Time decomposition method

The time-decomposition method (TDM) is based on four technical developments:

- **Domain decomposition along the time axis.** This provides excellent parallel computation scalability.
- **Periodic and general TDM models.**
  - Periodic TDM is used for steady-state simulation based on solving all time steps in one period simultaneously.
  - General TDM is used for general transient applications. It is based on solving a set of sequential subdivisions of all time steps, where each subdivision is being solved simultaneously.
- **Dedicated solvers.** To take full advantage of high-performance parallel computing, dedicated direct solvers and dedicated preconditioned iterative solvers have been developed to solve discretized block matrices of both TDM models very efficiently.
- **A robust algorithm.** To accommodate the nonlinearity, an efficient and reliable algorithm has been introduced to achieve excellent nonlinear convergence, maintaining exceptional parallel scalability and load balance.

The basic procedure of transient simulation includes spatial and temporal discretization of the physical equations. There are several approaches to do spatial discretization: finite differences, finite elements and finite volumes. The finite element method (FEM) is widely used in engineering practice because it can model complex inhomogeneous, anisotropic materials and represent complicated geometry using irregular grids. ANSYS Maxwell employs FEM to solve a set of Maxwell physical equations. FEM discretization produces a set of matrix differential equations. The typical temporal discretization includes backward Euler, Crank-Nicolson and theta-method. Because of nonlinearity, the matrices generally are dependent on the solution vectors, so an iteration method such as Newton-Raphson should be used to solve these nonlinear matrix equations. In this method, the nonlinear matrix equations are linearized for each nonlinear iteration. The linearized matrix equations may be solved by either a direct or an iterative matrix solver. The transient simulation is usually time consuming since it requires $N_t N_e$ number of matrix solving, where N_t is the number of time steps and N_e is the average number of nonlinear iterations. Provided that an algorithm can be made parallel, parallel computing can cut down the simulation time for the transient problems. For example, parallel computing can be applied to matrix solving at each time step. This can improve performance, but it is not always possible to make full use of all the parallel cores because the scaling is limited by various factors, such as communication among the cores. To achieve better parallel scalability, ANSYS Maxwell implements the domain decomposition along time-axis (TDM) to solve all time steps simultaneously, instead of solving a transient problem time-step by time-step.



Design Requirements

- Number of finite elements: 880,000
- DOF: 1,700,000
- Total time-steps: 600

Figure 2. 8kW-2000 rpm permanent magnet motor

Benchmark Summary

- Non-TDM Simulation Time: 7 Days
- Speedup Ratio: Max. 60x
- With Maxwell+HPC+SGI UV users can dramatically speed up their motor design transient simulations
- Significant speedup enhancement when MPI is combined with MP (hybrid HPC solution)
- Extremely large matrix size computation can be achieved by employing TDM
- When a larger numbers of cores and more RAM memory is available, larger designs and faster transient simulations can be performed

#Tasks*	#Total Cores	TDM Matrix Size	TDM Simulation Time
99	99	166.6 million	5h:21min
99	396	166.6 million	2h:38min

* Number of Tasks correspond to number of parallel computing MPI processing. Each Task can involve multi-core configuration to enable memory multithreading process.

Changing Mindset

In automotive, electric traction and energy generation markets there are multiple case studies where large design analysis is required. To obtain accurate and reliable performance predictions, the most detailed FE analysis is employed. Such studies are performed using magnetic transient (time-stepping) simulations. The 3-D magnetic transient solver can calculate:

- The end-field effect as end-winding field effect and/or the influence of different rotor and stator stack lengths on the overall torque and loss profile
- The skewed rotor/stator effect on motor performance
- Core loss prediction due to a magnetic field component normal to the lamination stack
- Induced magnetic field due to mechanical motion
- Effects of time-controlled current/voltage waveforms on operating point conditions
- Eddy-current effects induced onto conductive materials

Typical electric machine topologies and applications in which these phenomena are important are:

- Permanent magnet motors used in both hybrid-electric or electric traction and energy generation applications
- Induction motors used in any industrial application from heavy electric traction and marine propulsion to oil-gas applications
- Synchronous machines (with permanent magnets or wound rotor) used in electric energy generation
- Variable switch reluctance and synchronous reluctance motors used in high-efficiency traction applications

Computationally, due to their size and various design configurations (stator/rotor slots, pole pairs and winding topologies), all these electric machine topologies might introduce large design spaces (FEA degrees-of-freedom) and large time constants which require long time-stepping simulations. Moreover, these designs might employ large eddy effects on solid bars that generate slip for induction machines or damping for starting conditions or/and fault operations. All these phenomena are strongly dynamic and require large computational efforts as well.

Until now, such simulations were prohibitive due to total time computation required by traditional time-stepping approaches. With the new time decomposition method introduced by ANSYS Maxwell, all these simulations can be completed in a matter of hours.

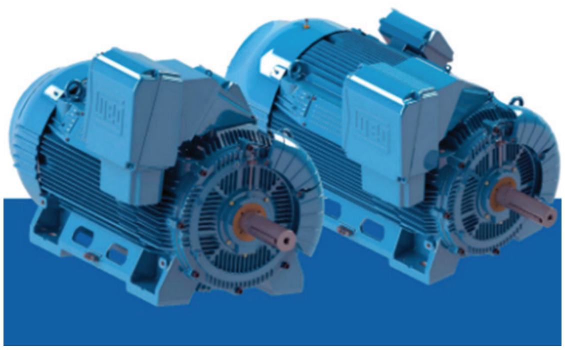


Figure 3. WEG medium-voltage induction motor

SGI UV 3000 Benchmark System used:
4 TB of Shared Memory @ 2133MHz
64 sockets; 640 cores Intel® Xeon® E5-4627v3 @ 2.6 GHz

Figure 4. WEG 3-phase MV induction motor and SGI UV 300 benchmark system.

Induction Motor Case Study

While detailed simulation design becomes a must for robust and optimized design analysis, to obtain multiple design points in a single day becomes more and more challenging. This was the case for WEG when it was strategizing its business initiatives to increase reliability with better margins by

- Maximizing possible operation time without the need of maintenance
- Maximizing operations in harsh conditions
- Producing motors with extra long life, reducing the failure rate and downtime
- Attaining high efficiency and energy savings

The problem was extremely difficult to solve in the time domain because both the rotor and stator, made of highly nonlinear electric steel, were designed with very complex geometries, including skewed rotor bars with large induced eddy-currents . The total number of time steps required to achieve an accurate solution at steady-state conditions made the entire case study prohibitive using traditional time-stepping simulations.
The combination of ANSYS Maxwell and the SGI UV platform delivered fast results when the level of design accuracy could not be compromised.

Following the results of the previous HPC study, WEG was able to reduce the total computation time by a factor of 70 times from almost 15 days of non-TDM (non-HPC) simulation.

The main contributor to the overall HPC performance is the number of parallel MPI processes deployed (# Tasks). At a given level of RAM memory, a combination of MPI and OpenMP (shared memory multithreading) might be employed to better utilize the HPC hardware profile, but this is not a requirement.

The time decomposition method provided not only a very fast transient solution of the dynamic performance of the motor design, but it also reduced the total decision time with multiple design points. For a given number of cores there is a linear correspondence between the total number of design points and computation time, making the ANSYS Maxwell transient solution suitable for robust design and optimization.

#Tasks	#Total Cores	TDM Matrix Size	TDM Simulation Time
16	128	16.5 million	16h:10min
32	256	34.1 million	9h:39min
64	512	69.3 million	6h:44min
128	1024	139.7 million	5h:14min

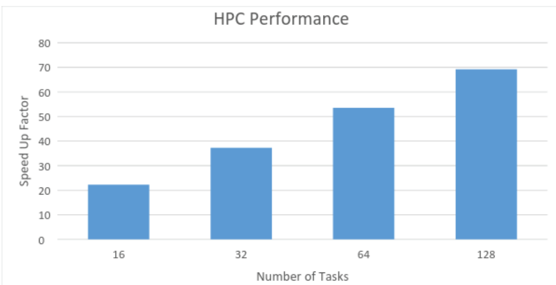


Figure 5. HPC performance

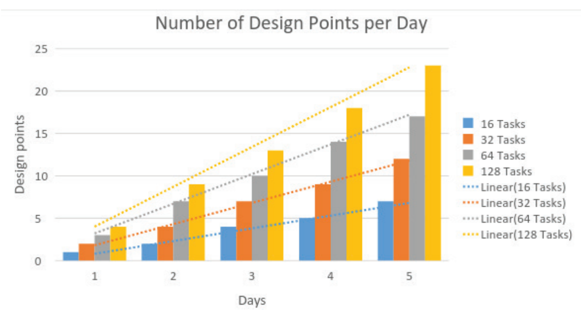


Figure 6. Total number of design points available per day for robust design analysis

Summary

The new time decomposition method within ANSYS Maxwell allows engineers to solve time-steps simultaneously instead of sequentially. Simulations that previously required weeks or several hours of computation time are now completed in a matter of hours or several minutes.

On the hardware side, SGI's UV 3000 advanced symmetric multiprocessing (SMP) computer system eliminates the risk of simulation failure and lost time due to insufficient computing memory, and enables users to perform more Maxwell low-frequency electromagnetic simulations in less time.

For More Information on ANSYS Maxwell:
ansys.com/Products/Electronics/ANSYS-Maxwell

For more information on SGI Solutions for ANSYS Customer please visit the ANSYS/SGI Partner page:
ansys.com/About-ANSYS/Partner-Programs/High-Performance-Computing-Partners/SGI

ANSYS, Inc.
Southpointe
2600 ANSYS Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com