

MATLAB EXPO

大规模物理系统模型并行仿真加速

周前程, MathWorks



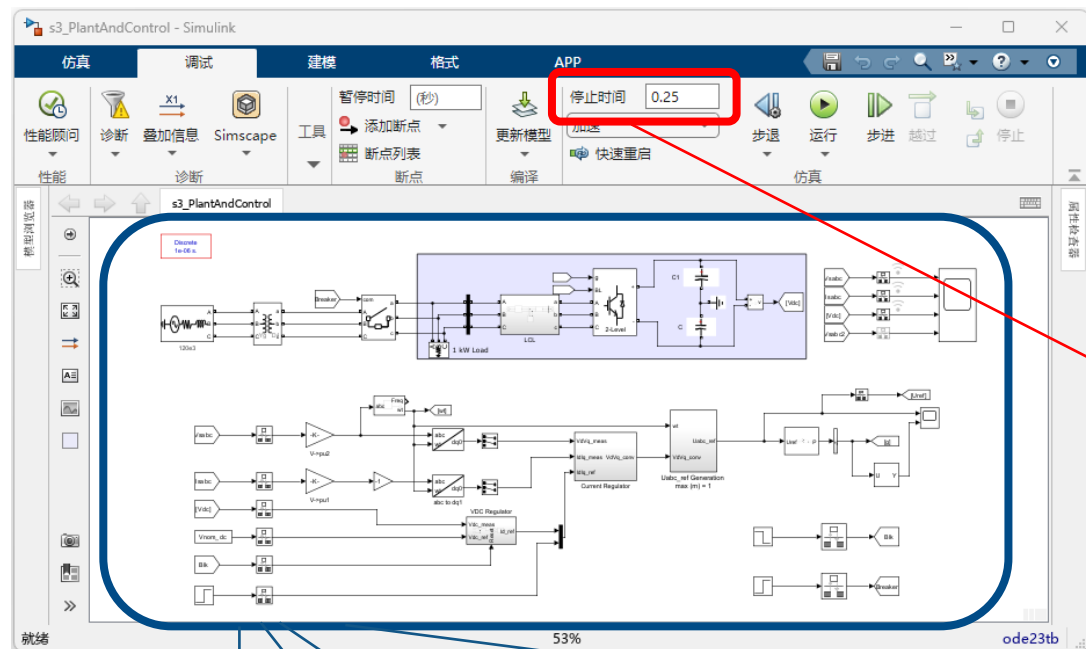
你在用.....吗？

- Simulink ?
- Simscape ?
- 你有遇到仿真速度问题吗 ?
- 遇到速度问题怎么办 ?

Key Take Away

- 影响仿真速度相关的因素
- 仿真速度优化方法
- 加速模式的使用
- 模型解耦降低物理模型复杂度
- 利用多核 CPU 加速仿真

影响仿真速度相关的因素



模型复杂度

迭代次数

步长大小

定步长

变步长 0s

0.25s

- 仿真时长/仿真步长 – 迭代次数
- 模型规模 – 每个时间步耗费时间
- 仿真模式 – 代码加速
- 模型编译
- 硬件资源

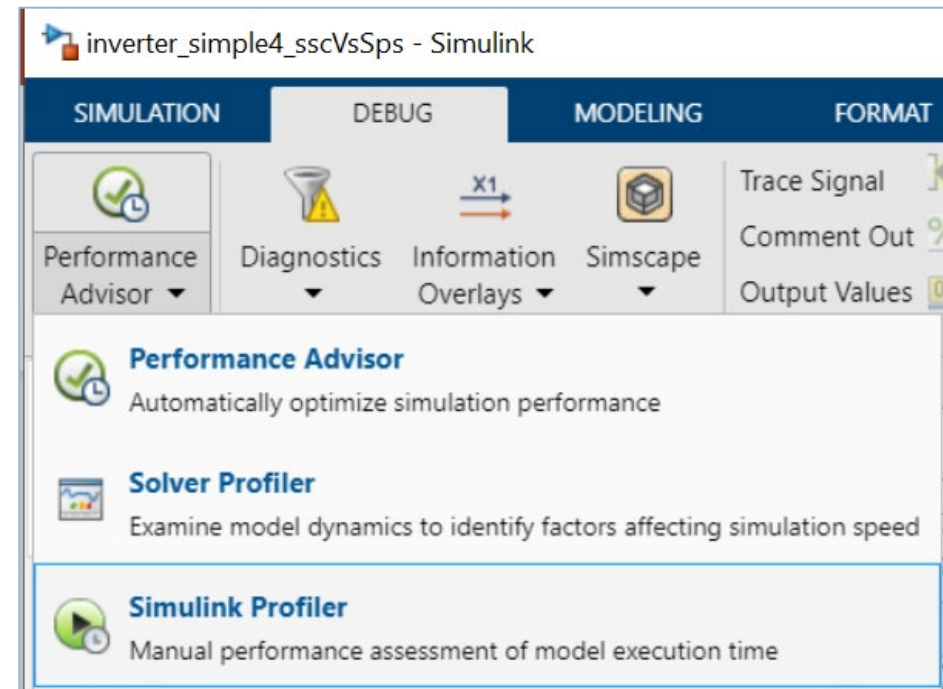
仿真速度优化 – 诊断工具

量化模型仿真时间，识别瓶颈

Solver Profiler

Simulink Profiler

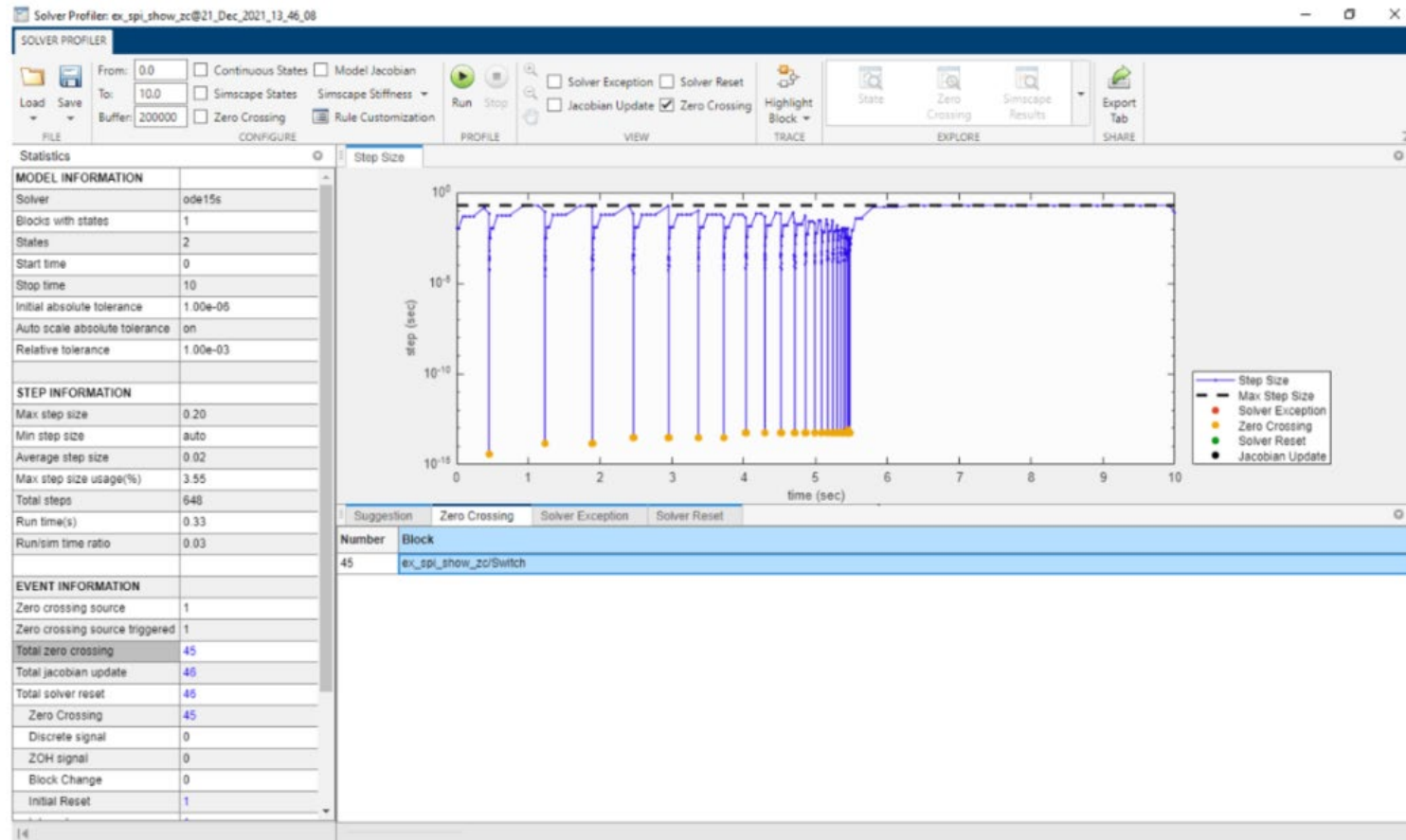
Performance advisor



仿真速度优化 – 诊断工具

Solver Profiler

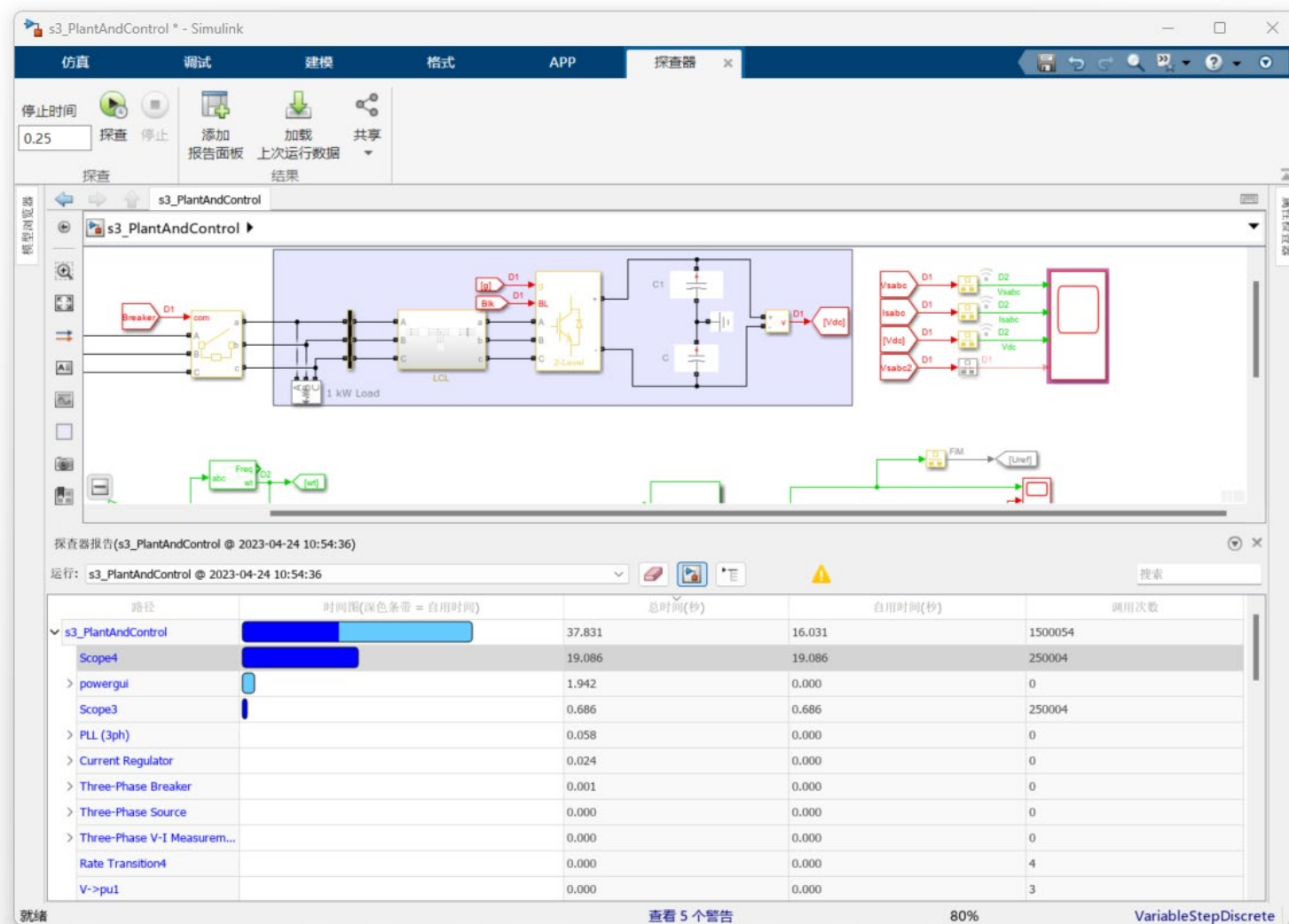
- 步长统计
- 检测事件
 - Zero-crossing events
 - Solver exception events
 - Solver reset events
 - Jacobian computation events



仿真速度优化 – 诊断工具

Simulink Profiler

- 统计模块仿真耗时
- 调用频次



仿真速度优化 – 诊断工具

Performance Advisor

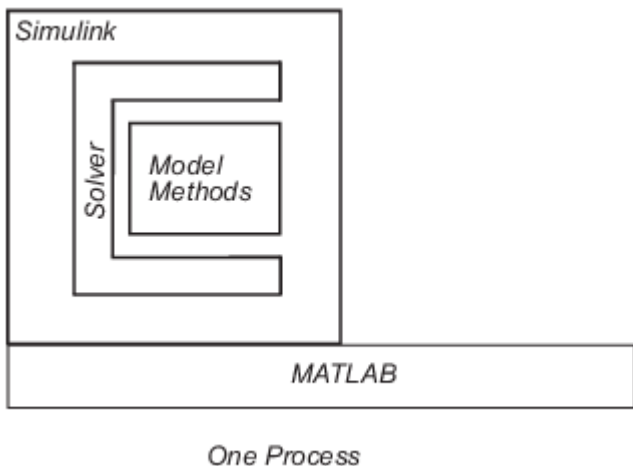
The screenshot displays the Simulink Performance Advisor interface. The main window shows a list of diagnostic checks under the '性能顾问' (Performance Advisor) category. The '标识示波器' (Identify Oscilloscopes) check is highlighted, showing a warning icon and a message: '示波器会影响仿真性能。要提高仿真性能，请关闭并注释掉示波器。' (Oscilloscopes affect simulation performance. To improve simulation performance, please close and comment out the oscilloscopes.)

The '标识示波器' check results table is as follows:

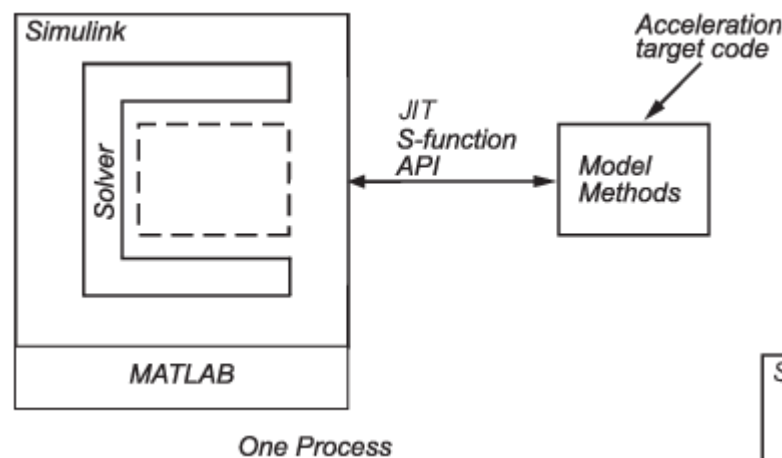
模型中的示波器		
s3_PlantAndControl/Current Regulator/Scope	注释掉/取消注释	打开/关闭
s3_PlantAndControl/Scope3	注释掉/取消注释	打开/关闭
s3_PlantAndControl/Scope4	注释掉/取消注释	打开/关闭

Below the table, there are buttons for '全部修改' (Apply All) and '帮助(H)' (Help).

仿真模式

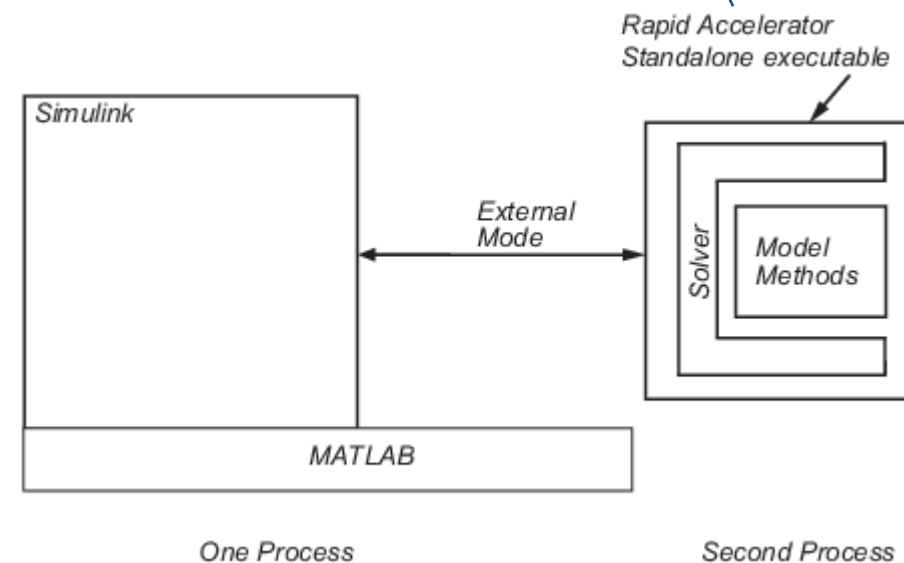


Normal – 普通



Accelerator – 加速

将模型生成代码并编译



Rapid Accelerator – 快速加速

仿真模式

普通模式

探查器报告(s3_PlantAndControl @ 2023-05-11 13:12:55)

运行: s3_PlantAndControl @ 2023-05-11 13:12:55

路径	时间图(深色条带 = 自用时间)	总时间(秒)	自用时间(秒)	调用次数
simulate(s3_PlantAndControl)		126.630	0.000	1
simulationPhase		122.491	10.289	1
compilePhase		3.610	3.610	1
terminationPhase		0.291	0.005	1
initializationPhase		0.237	0.043	1

加速模式

探查器报告(s3_PlantAndControl @ 2023-05-11 13:09:51)

运行: s3_PlantAndControl @ 2023-05-11 13:09:51

路径	时间图(深色条带 = 自用时间)	总时间(秒)	自用时间(秒)	调用次数
simulate(s3_PlantAndControl)		50.137	0.000	1
simulationPhase		45.355	7.034	1
compilePhase		4.094	4.094	1
initializationPhase		0.358	0.120	1
terminationPhase		0.330	0.004	1

- 仿真时间缩短

- 编译时间增加

- 总时间缩短

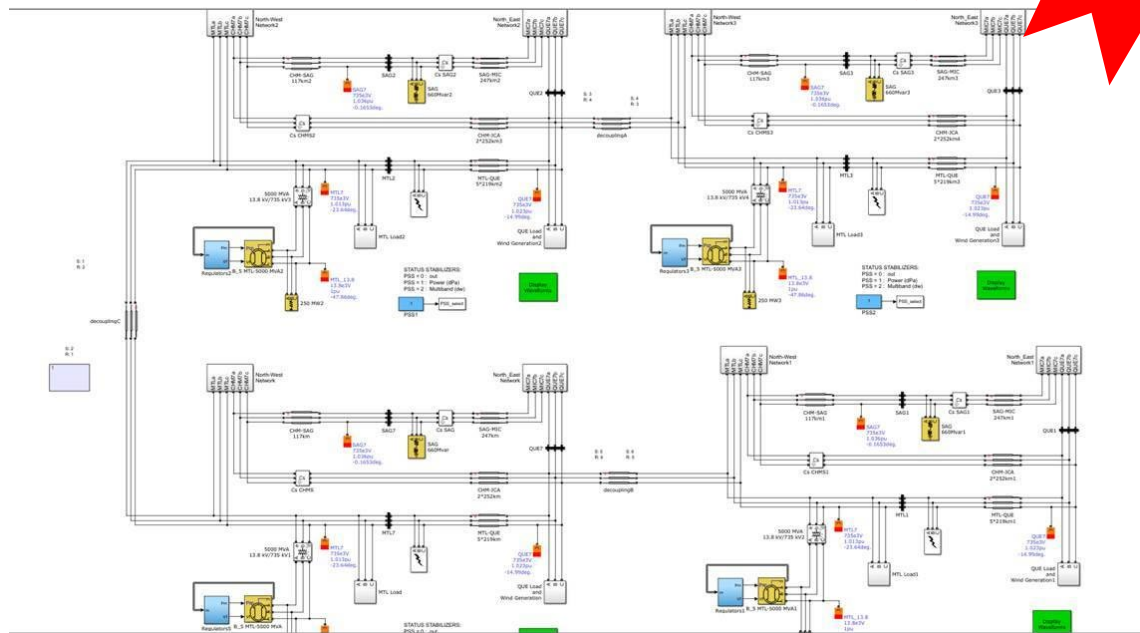
使用合适的方法对模型仿真速度进行优化

得到“合理”的速度

但是。。。

模型规模持续增加带来新的调整

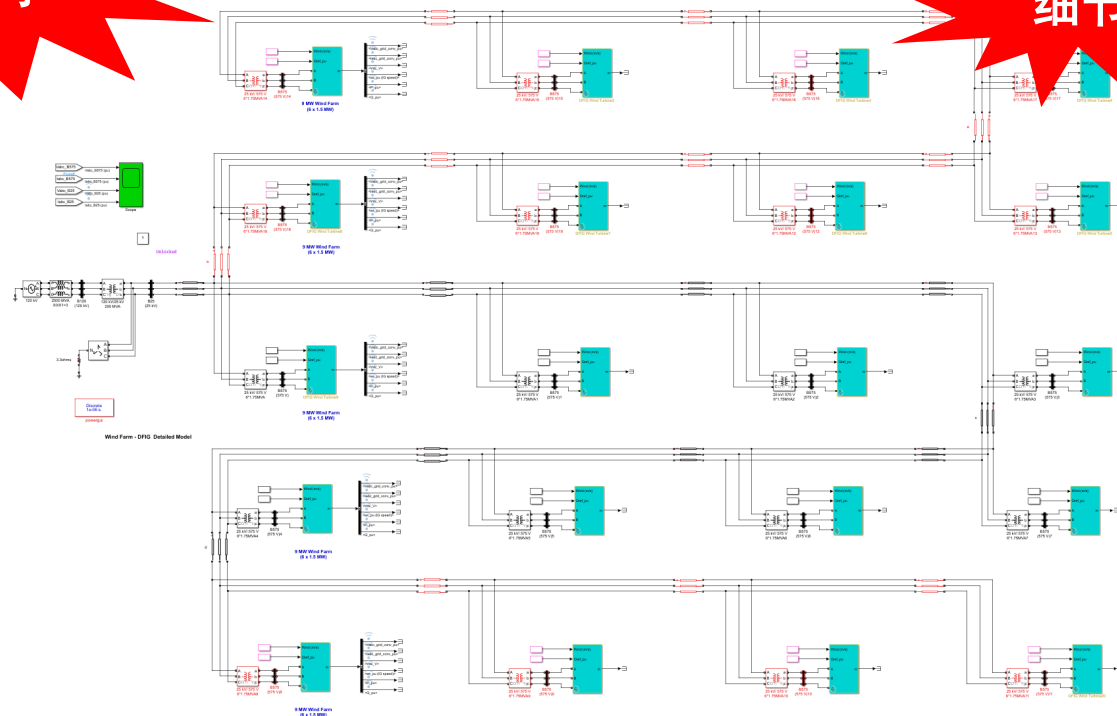
大电网电磁暂态仿真



长时间

包含开关特性风机构成的大型风电场

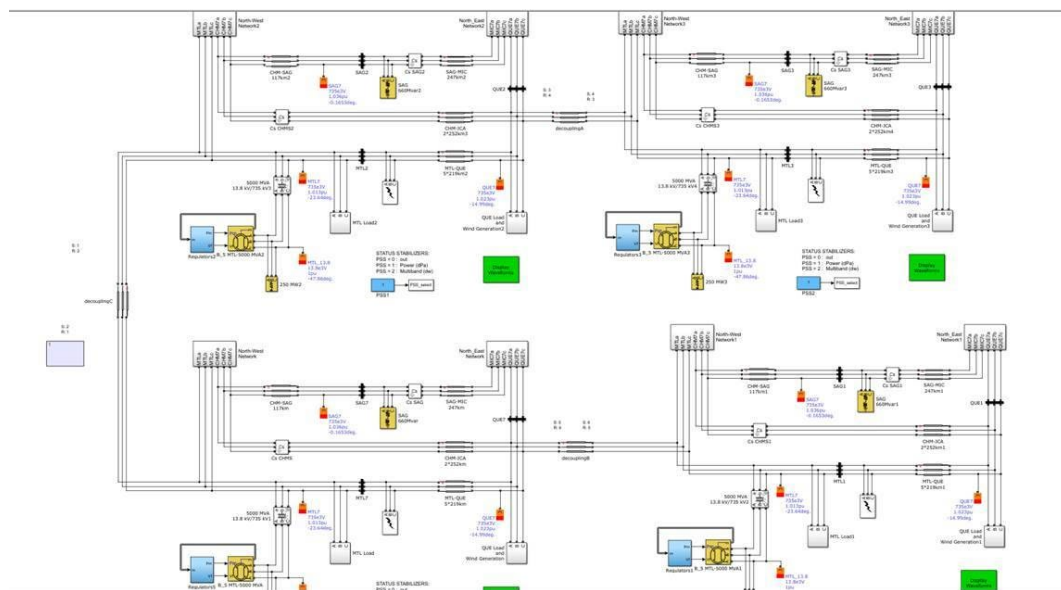
细节



模型规模 : 4*29 bus system
 仿真步长 : 75us
 仿真时长 : 4.5s
 仿真耗时 : 320s

模型规模 : 20 DFIG WT
 仿真步长 : 1us
 仿真时长 : 0.2s
 仿真耗时 : 1000s

模型规模持续增加带来新的调整



- 多数时候仿真是单线程的
- 无法最大化利用多核CPU

仿真中主要一个核中运行

CPU Intel(R) Core(TM) i5-10400 CPU @ 2.90GHz

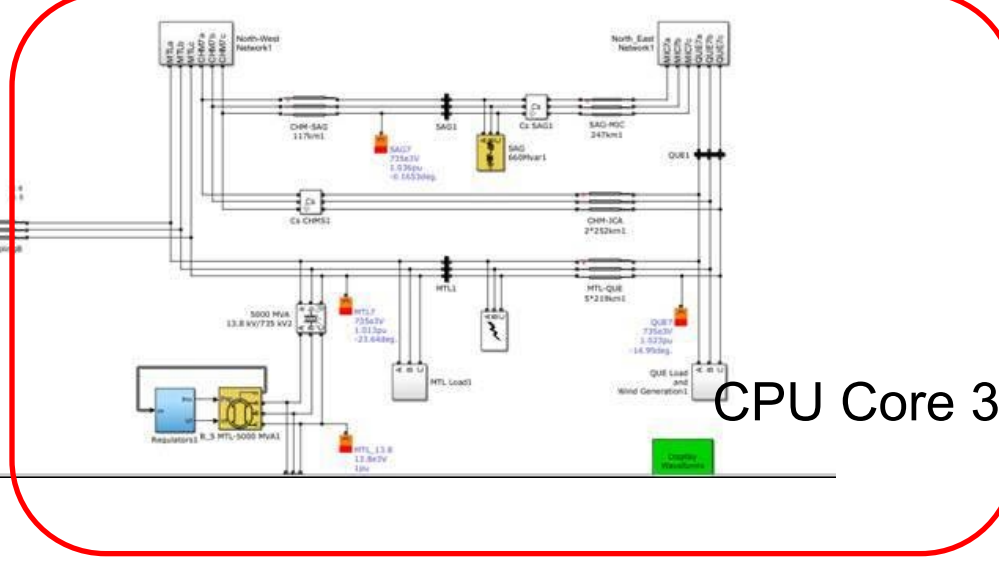
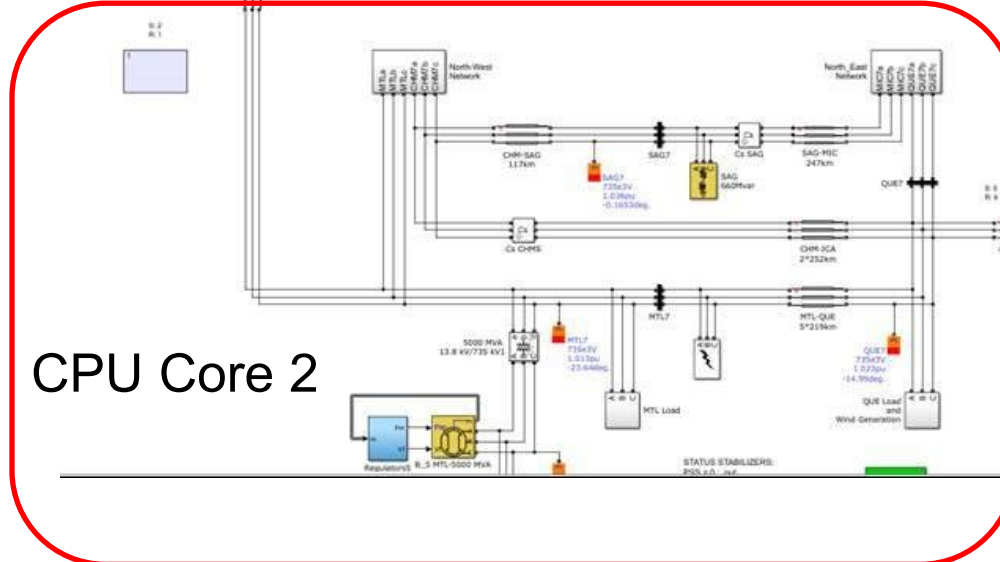
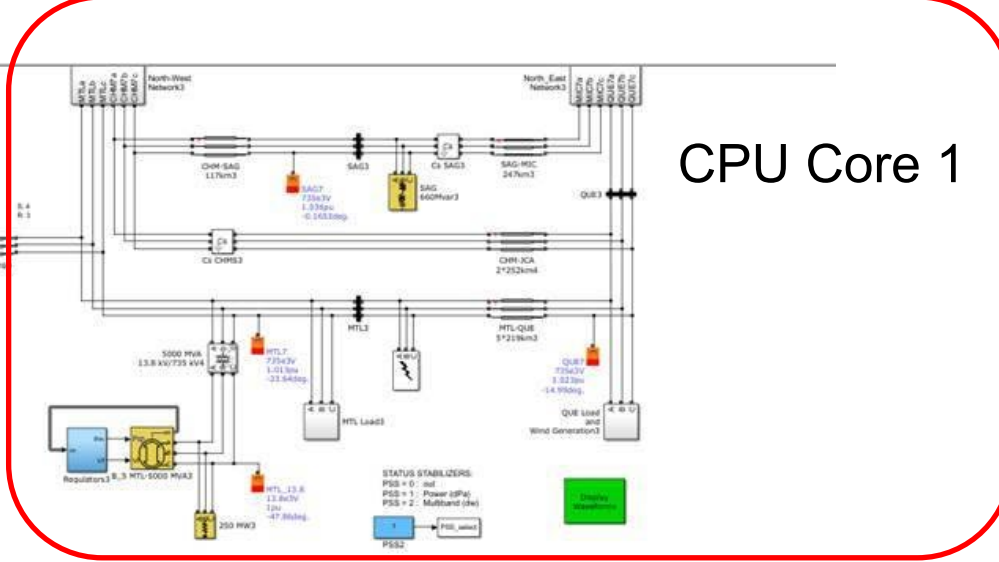
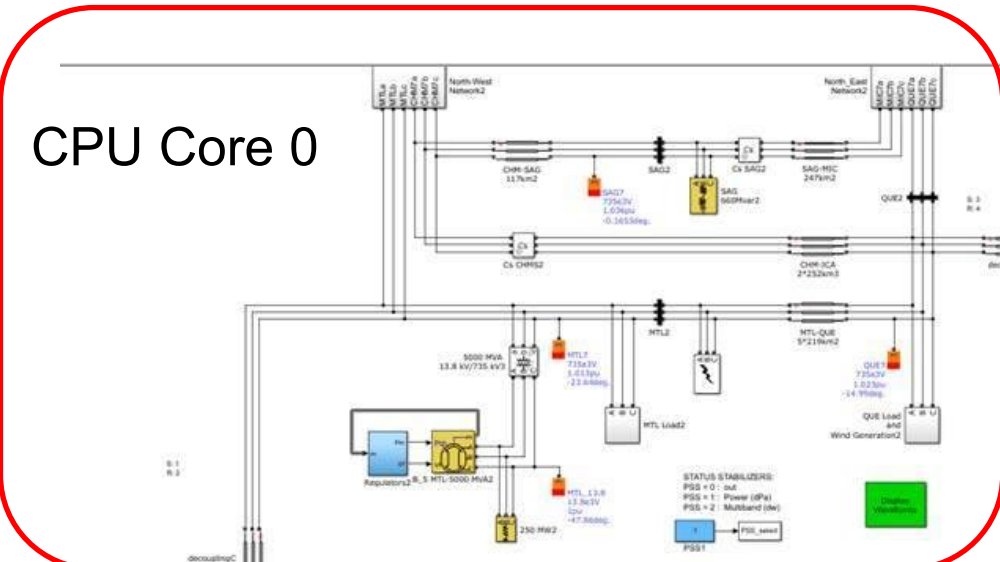
60秒内的利用率%

100%



解决方案

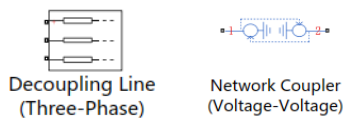
并行仿真



解决方案

模型解耦

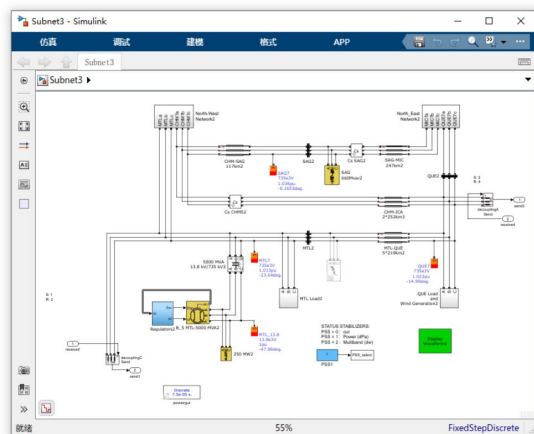
- 物理模型解耦



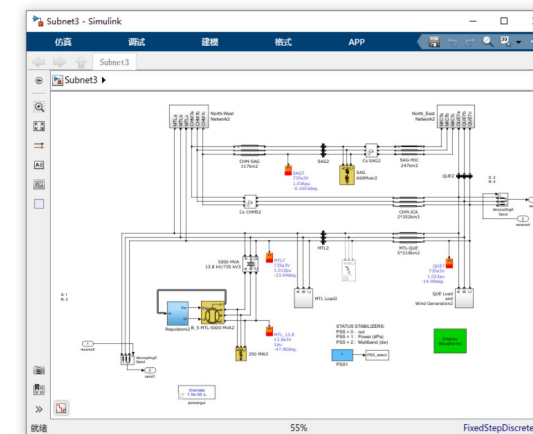
- 将模型分割成若干个子模型
- 利用‘PSIO’建立模型间通信



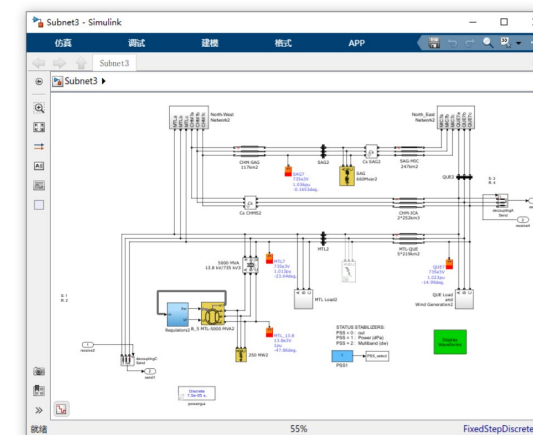
CPU Core 1



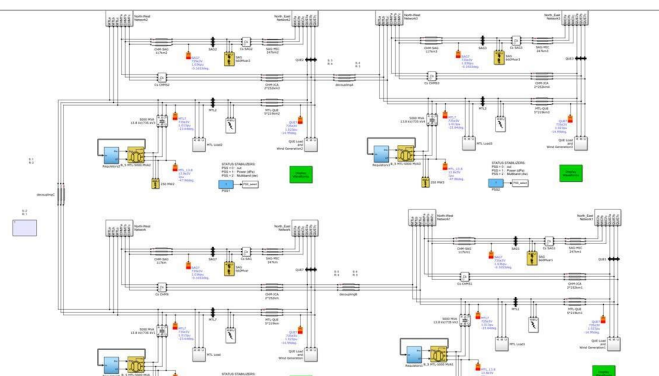
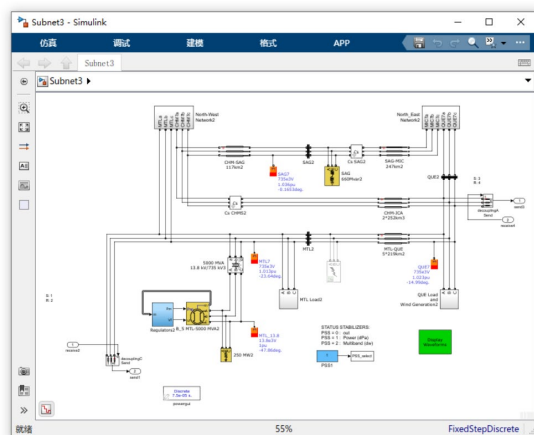
CPU Core 2



CPU Core 4



CPU Core 3



解决方案

启动多核仿真

- 使用 Parallel Computing Toolbox 启动并行仿真



→
CPU 利用率变得更高



解决方案

并行仿真控制面板

仿真控制器

Parallel Simulation

Controls

Initialize Start Simulation

Plot Compare

Import Results Clear Results

Simulation Time (s) 0.2

Simulation Mode accelerator

Models

Select models Open models

power_wind_dfig_det_serial_x20_p1
power_wind_dfig_det_serial_x20_p2
power_wind_dfig_det_serial_x20_p3
power_wind_dfig_det_serial_x20_p4
power_wind_dfig_det_serial_x20_p5

Results

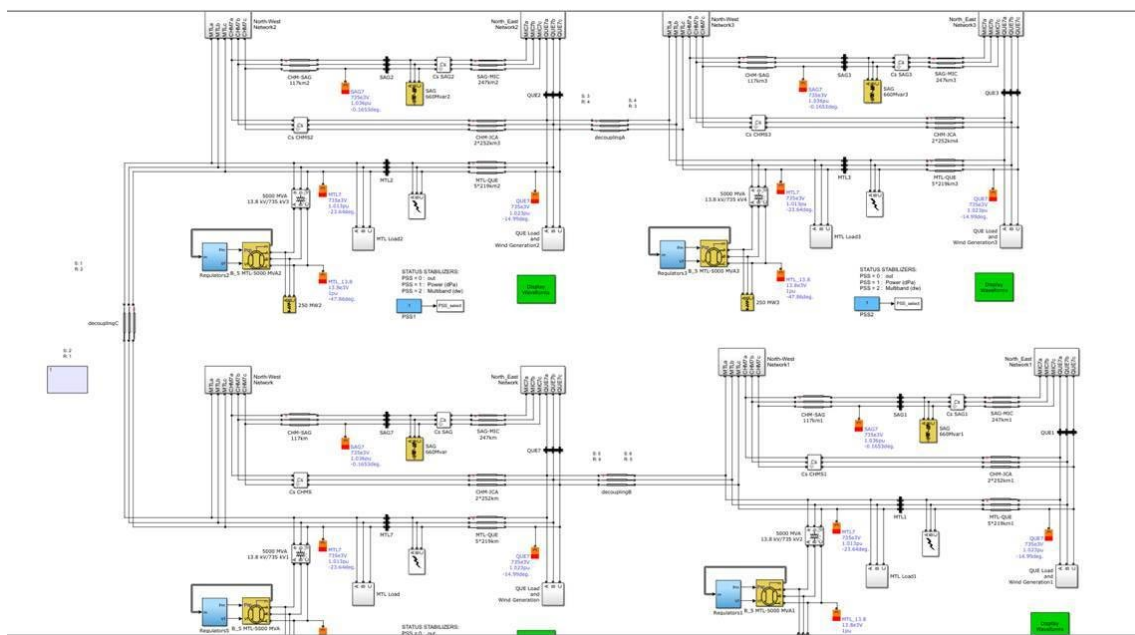
1	power_wind_dfig_det_serial_x20...	<labc_grid_conv_p...
2	power_wind_dfig_det_serial_x20...	<P_pu>
3	power_wind_dfig_det_serial_x20...	<Q_pu>
4	power_wind_dfig_det_serial_x20...	<Vabc_grid_conv_...
5	power_wind_dfig_det_serial_x20...	<Vdc_V>
6	power_wind_dfig_det_serial_x20...	<wr_pu (IG speed)>
7	power_wind_dfig_det_serial_x20...	<labc_grid_conv_p...
8	power_wind_dfig_det_serial_x20...	<P_pu>
9	power_wind_dfig_det_serial_x20...	<Q_pu>
10	power_wind_dfig_det_serial_x20...	<Vabc_grid_conv_...
11	power_wind_dfig_det_serial_x20...	<Vdc_V>
12	power_wind_dfig_det_serial_x20...	<wr_pu (IG speed)>
13	power_wind_dfig_det_serial_x20...	<labc_grid_conv_p...
14	power_wind_dfig_det_serial_x20...	<P_pu>
15	power_wind_dfig_det_serial_x20...	<Q_pu>
16	power_wind_dfig_det_serial_x20...	<Vabc_grid_conv_...
17	power_wind_dfig_det_serial_x20...	<Vdc_V>
18	power_wind_dfig_det_serial_x20...	<wr_pu (IG speed)>
19	power_wind_dfig_det_serial_x20...	Vabc_B25 (pu)
20	power_wind_dfig_det_serial_x20...	labc_B25 (pu)
21	power_wind_dfig_det_serial_x20...	<labc_grid_conv_p...
22	power_wind_dfig_det_serial_x20...	<P_pu>
23	power_wind_dfig_det_serial_x20...	<Q_pu>
24	power_wind_dfig_det_serial_x20...	<Vabc_grid_conv_...
25	power_wind_dfig_det_serial_x20...	<Vdc_V>

仿真结果

模型选择

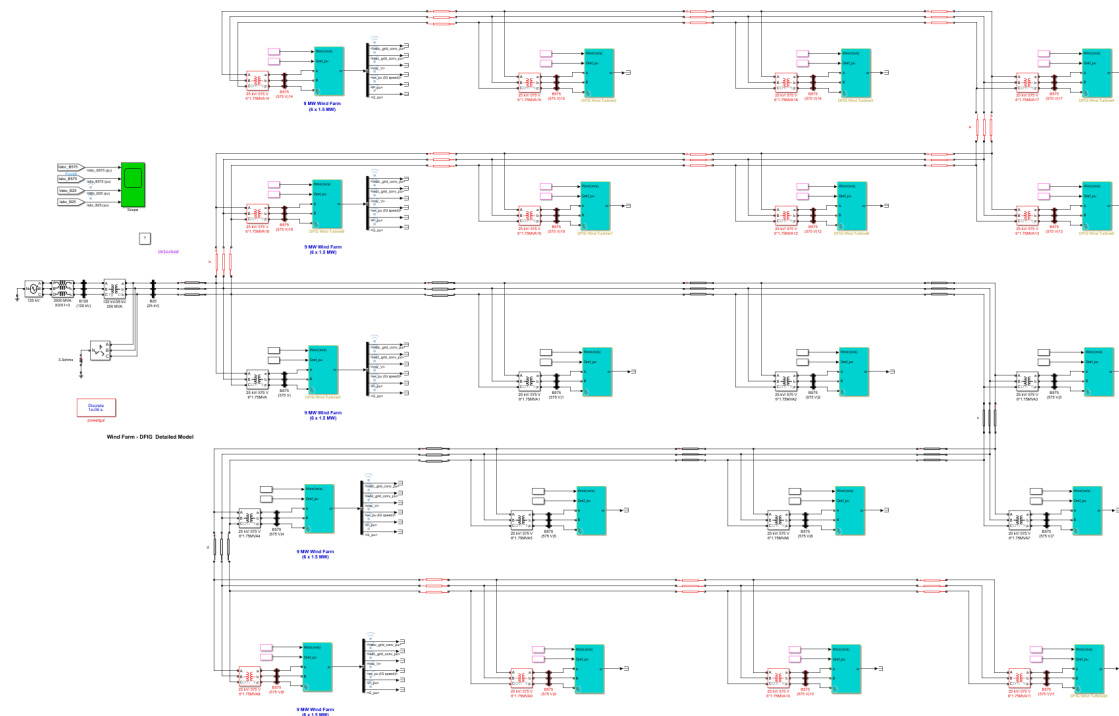
测试案例

案例1：大电网电磁暂态仿真



模型规模 : 4*29 bus system
 仿真步长 : 75us
 仿真时长 : 4.5s
 仿真耗时 : 320s

案例2：包含开关特性风机构成的大型风电场

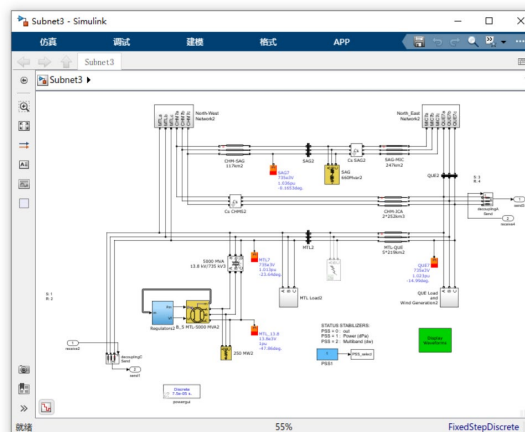


模型规模 : 20 DFIG WT
 仿真步长 : 1us
 仿真时长 : 0.2s
 仿真耗时 : 1000s

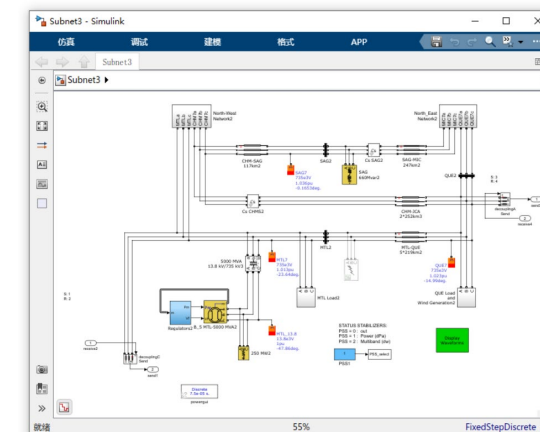
案例1：大电网电磁暂态仿真

- 大电网模型拆分成4个部分，分别运行到4个CPU核

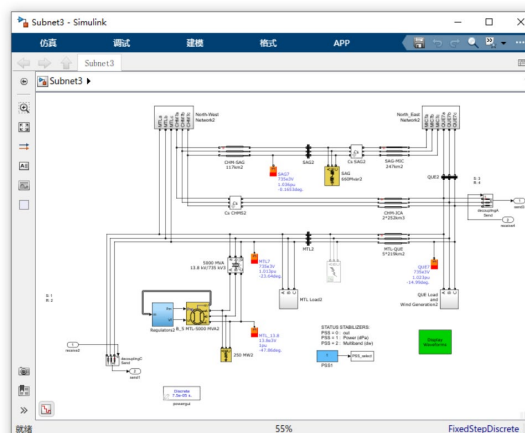
CPU Core 1



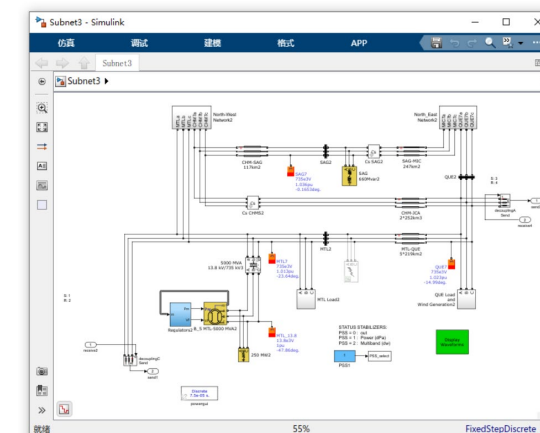
CPU Core 2



CPU Core 3



CPU Core 4



工程快捷方式

新建 整理 管理 快捷方式 组

power_LFnetwork_29bus_x4 power_LFnetwork_29bus_x4_p power_LFnetwork_29bus_x4_p_mf

ParallelSimulationControlPanel Subnet_p1 Subnet_p2 Subnet_p3 Subnet_p4

常规 S2 S3 S4

视图 所有 工程 (36) 已修改 (37) 布局: 树

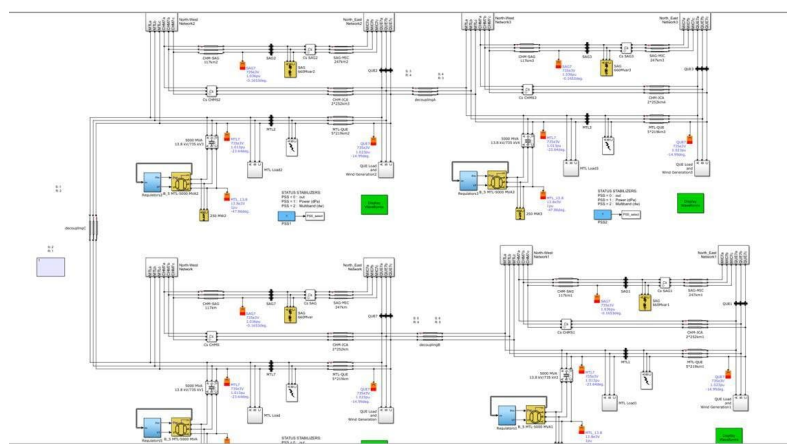
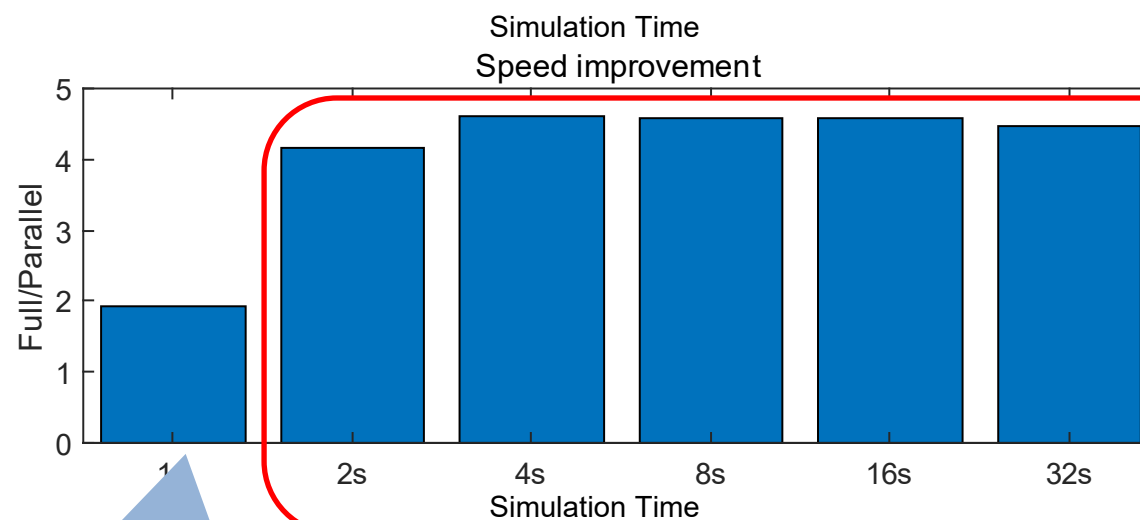
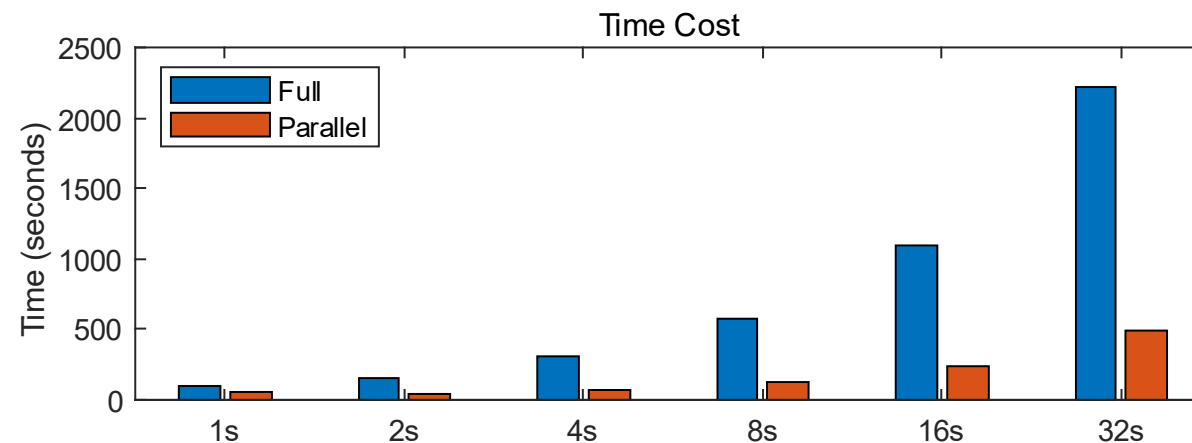
名称	状态	分类	SVN	修订版
app	✓		■	2
icon.PNG	·		○	
ParallelSimulationControlPanel.mlapp	✓	设计	○	2
Doc	✓		●	1
Lib	✓		●	1
Model	✓		■	1
power_LFnetwork_29bus_x4_p.slx	✓	设计	○	1
power_LFnetwork_29bus_x4_p.slx.r2021a	·		○	
power_LFnetwork_29bus_x4_p_mf.slx	✓	设计	■	1
power_LFnetwork_29bus_x4.slx	✓	设计	■	1
power_LFnetwork_29bus_x4.slx.r2021a	·		○	
Subnet1.slx	✓	设计	●	2
Subnet1.slx.r2021a	·		○	
Subnet2.slx	✓	设计	●	1
Subnet3.slx	✓	设计	●	1
Subnet4.slx	✓	设计	●	1
Subnet_p1.slx	✓	设计	■	2
Subnet_p2.slx	✓	设计	■	2
Subnet_p3.slx	✓	设计	■	2
Subnet_p4.slx	✓	设计	■	2
resources	·		■	1
Result	·		○	
Script	✓		■	1
Work	·		○	
MultiCoreDemo.prj	·		●	1

标签 分类

案例1：大电网电磁暂态仿真

测试结果: 速度提升

- 完整模型（Full）拆分成四个并行模型（Parallel）
- 四核加速
- 并行模型比完整模型快四倍
- 长时仿真结果更好
- PCT 需要时间做初始化



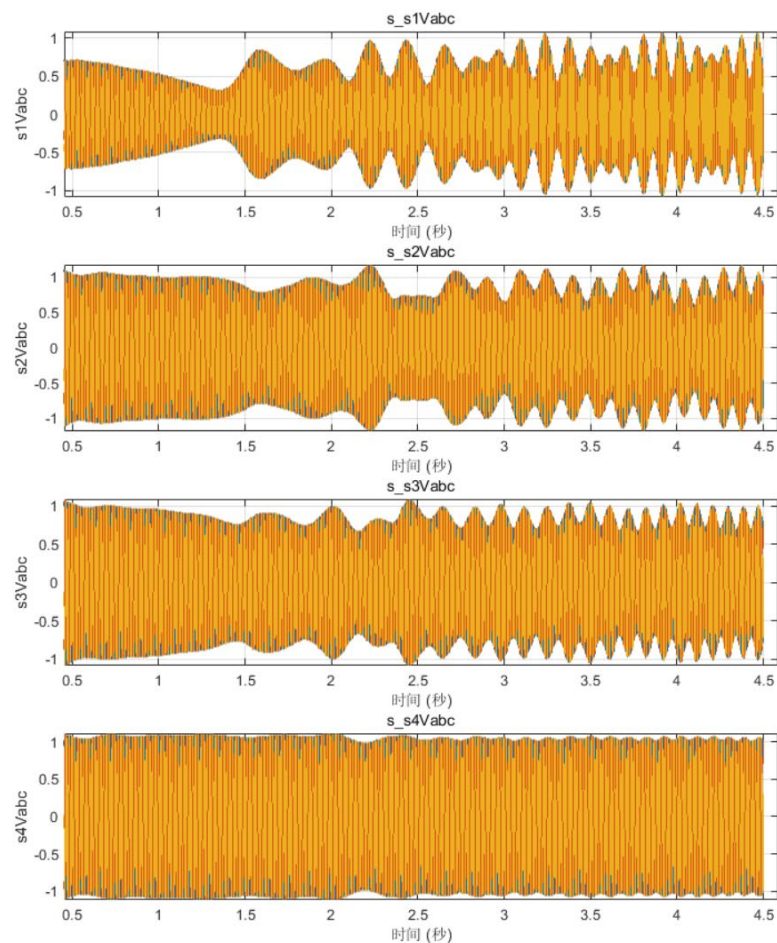
PCT 初始化占比高

速度提升倍数

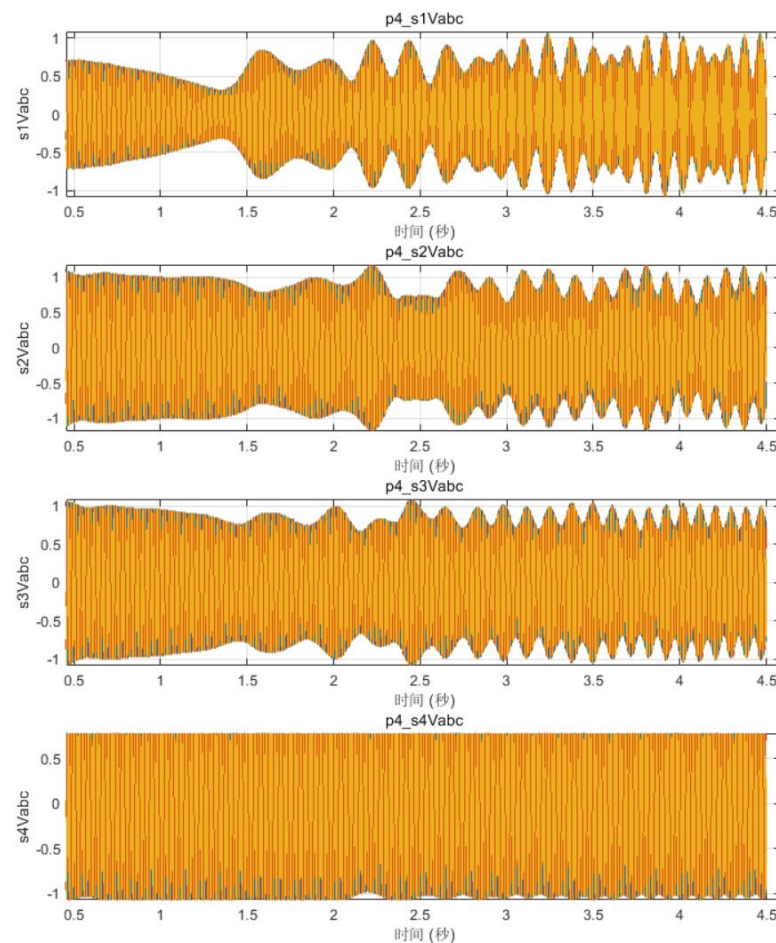
案例1：大电网电磁暂态仿真

测试结果：电气信号比较

Full model



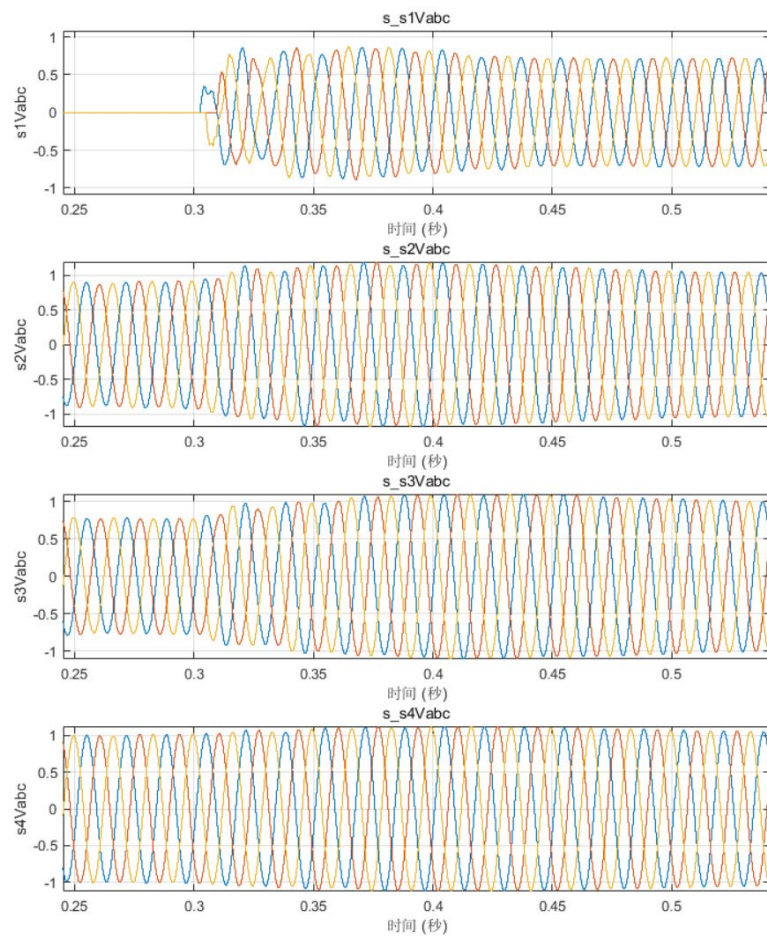
Parallel 4 models



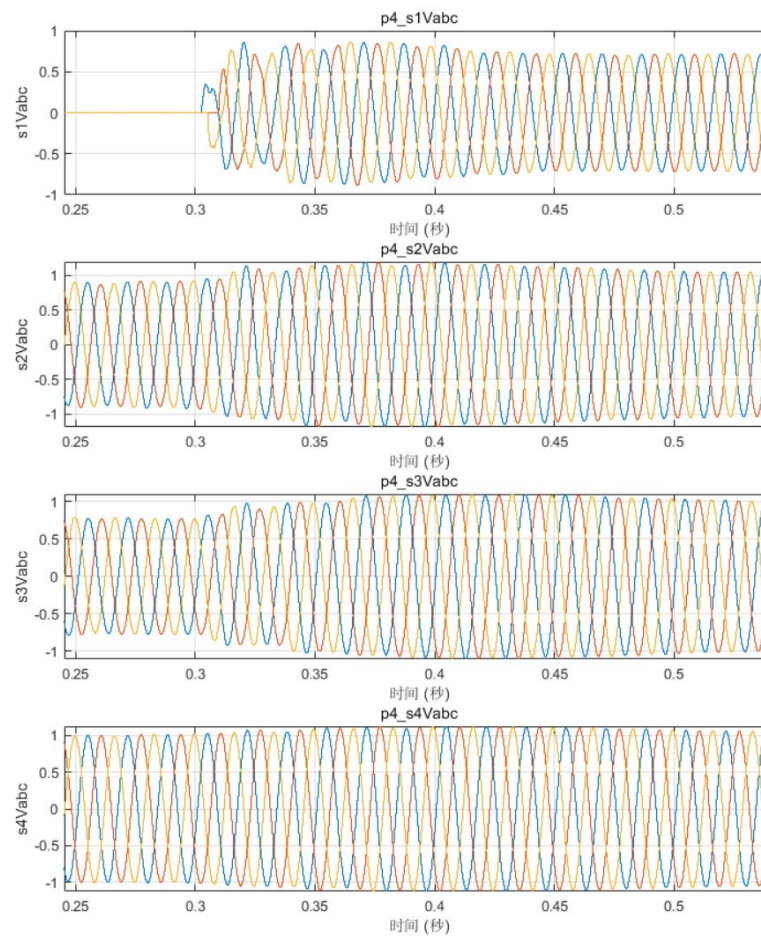
案例1：大电网电磁暂态仿真

测试结果：电气信号比较

Full model

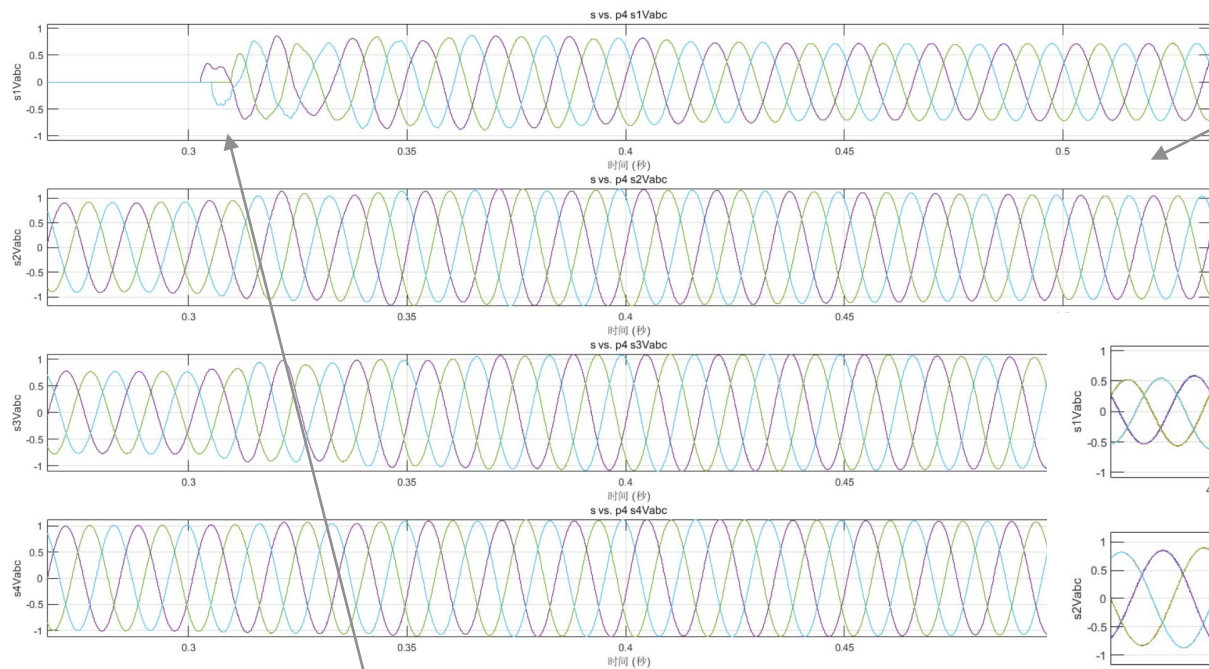


Parallel 4 models



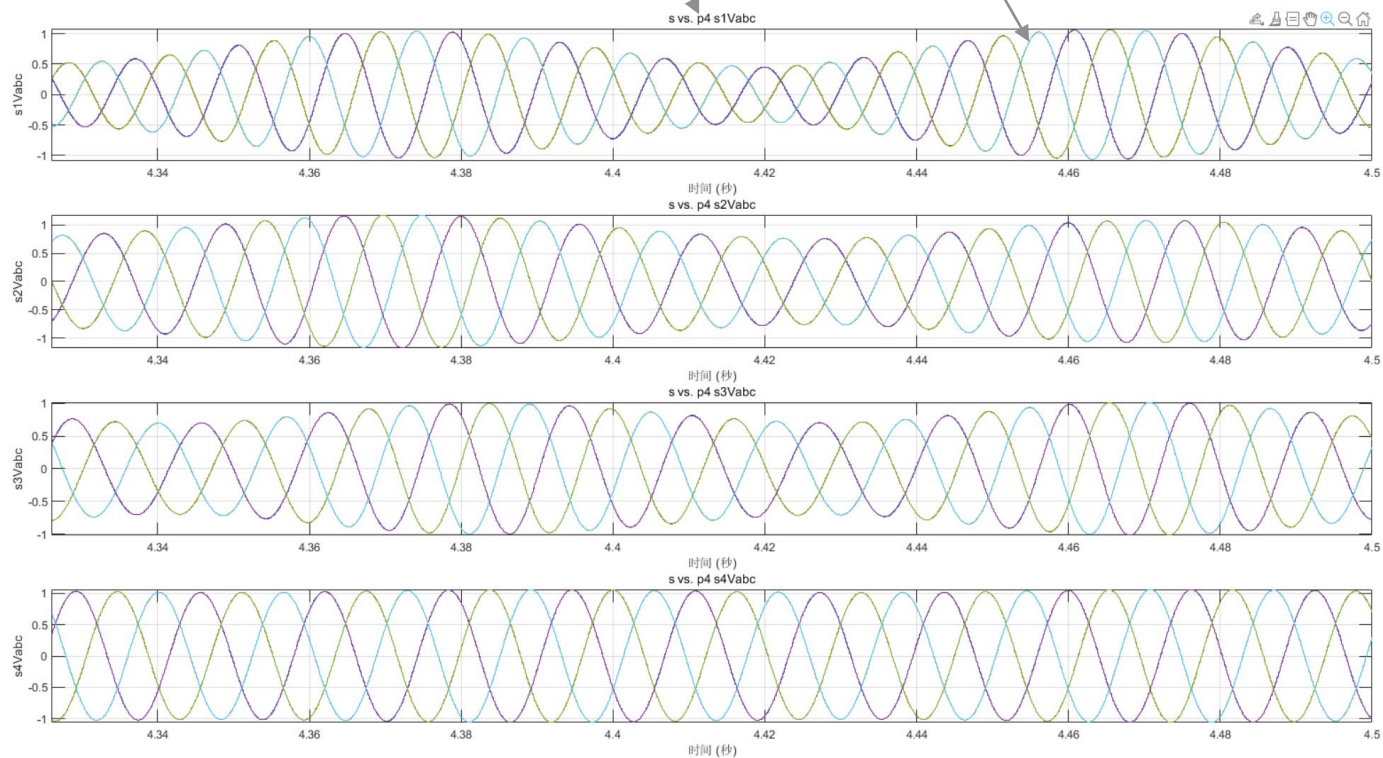
案例1：大电网电磁暂态仿真

测试结果：电气信号比较



暂态过程

完整模型和并行模型结果在同一幅图里重合了

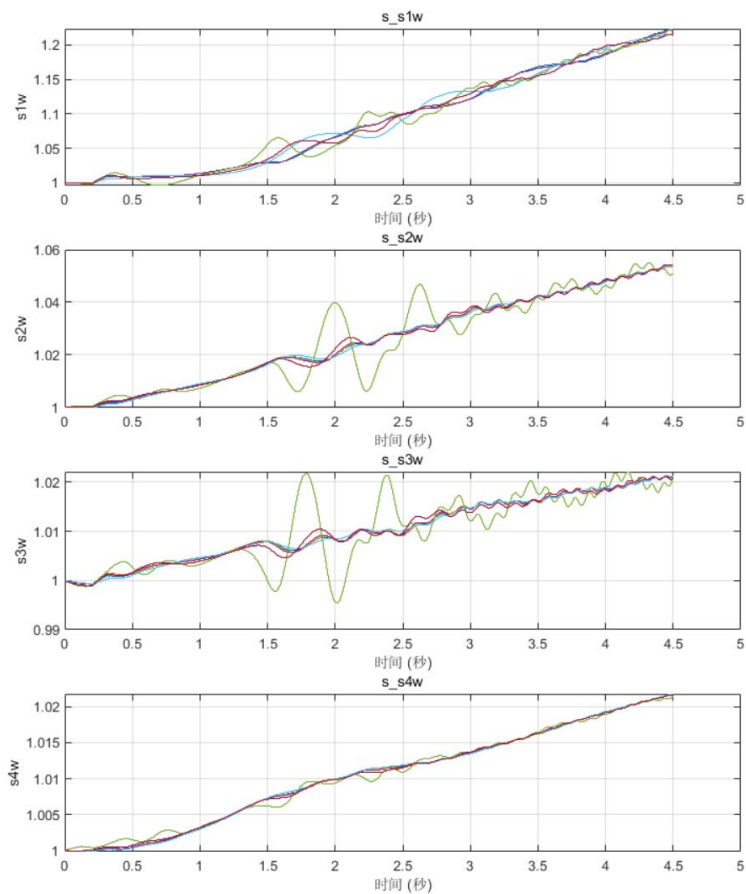


长时

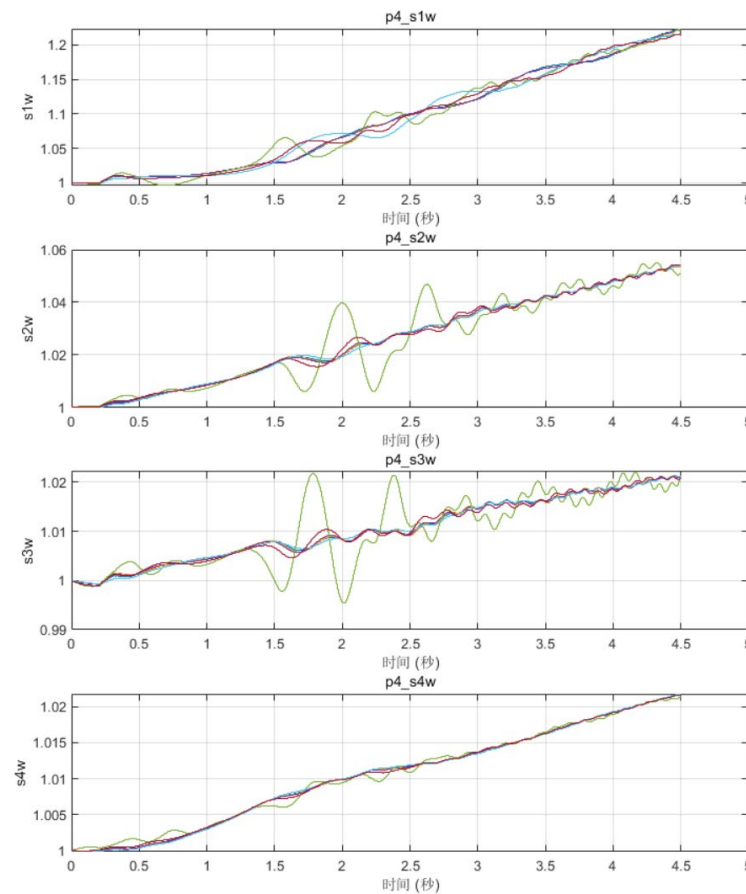
案例1：大电网电磁暂态仿真

测试结果：机械转速

Full model

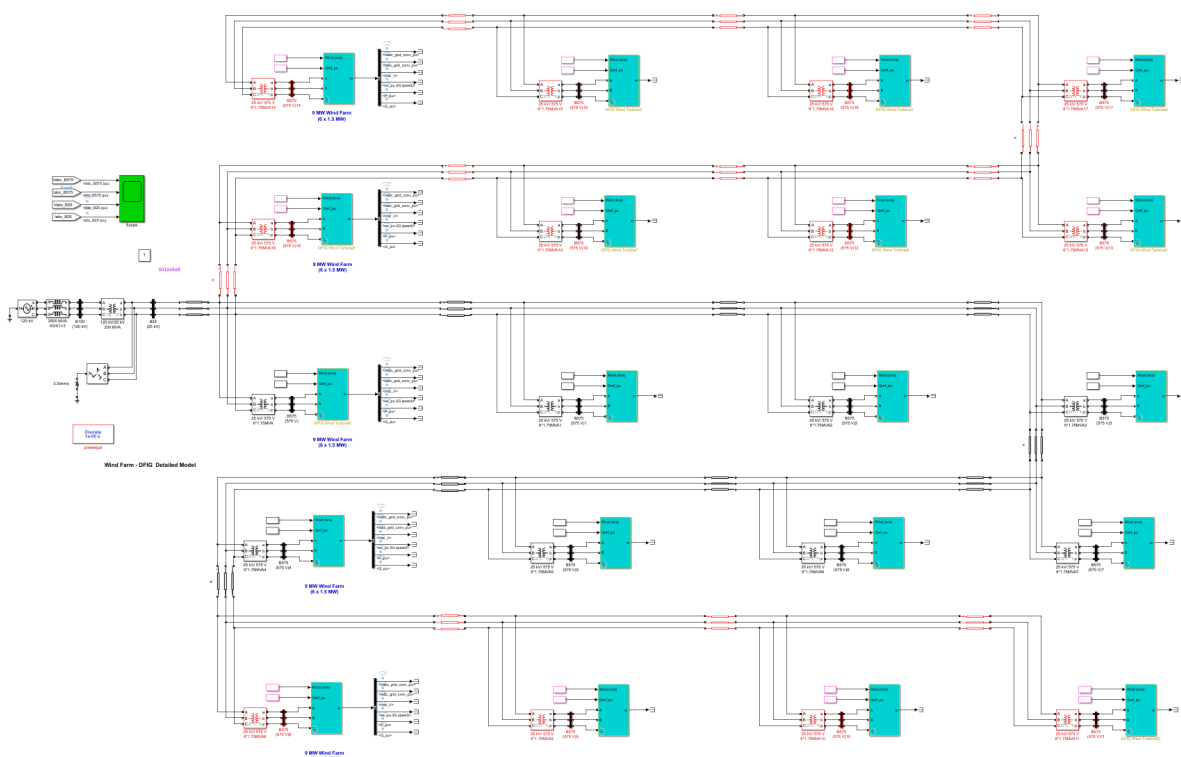


Parallel 4 models



案例2：风电场测试

20x DFIG 风电场 分成五组，拆分成五个模型，
在六核CPU上进行并行仿真



Full Model



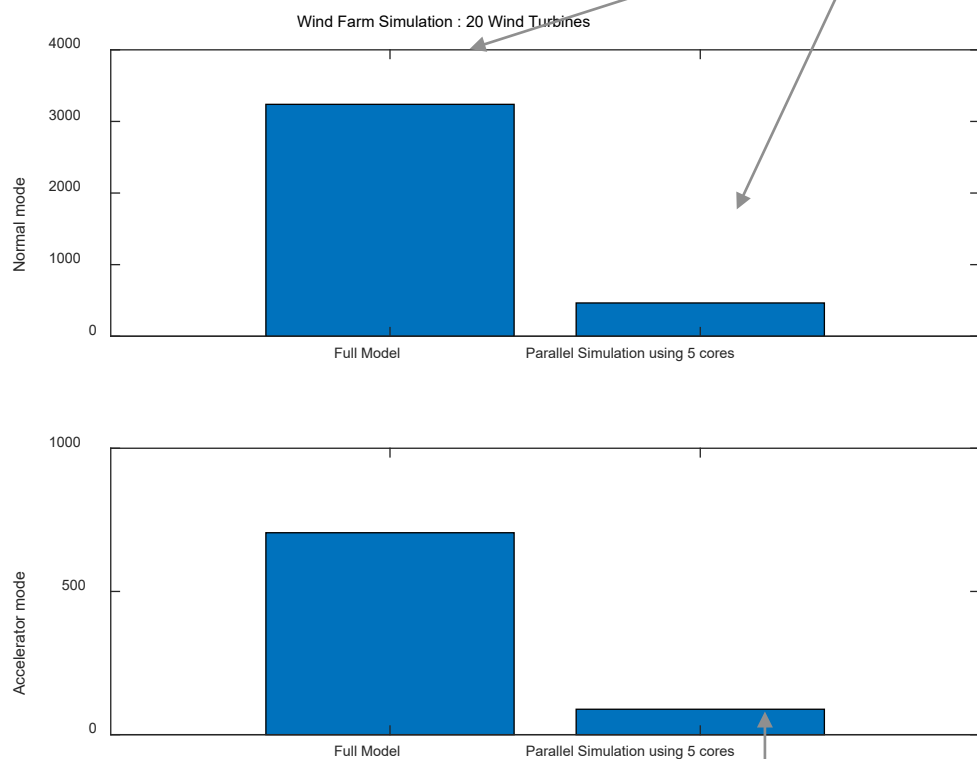
Parallel Models

案例2：风电场测试

测试结果

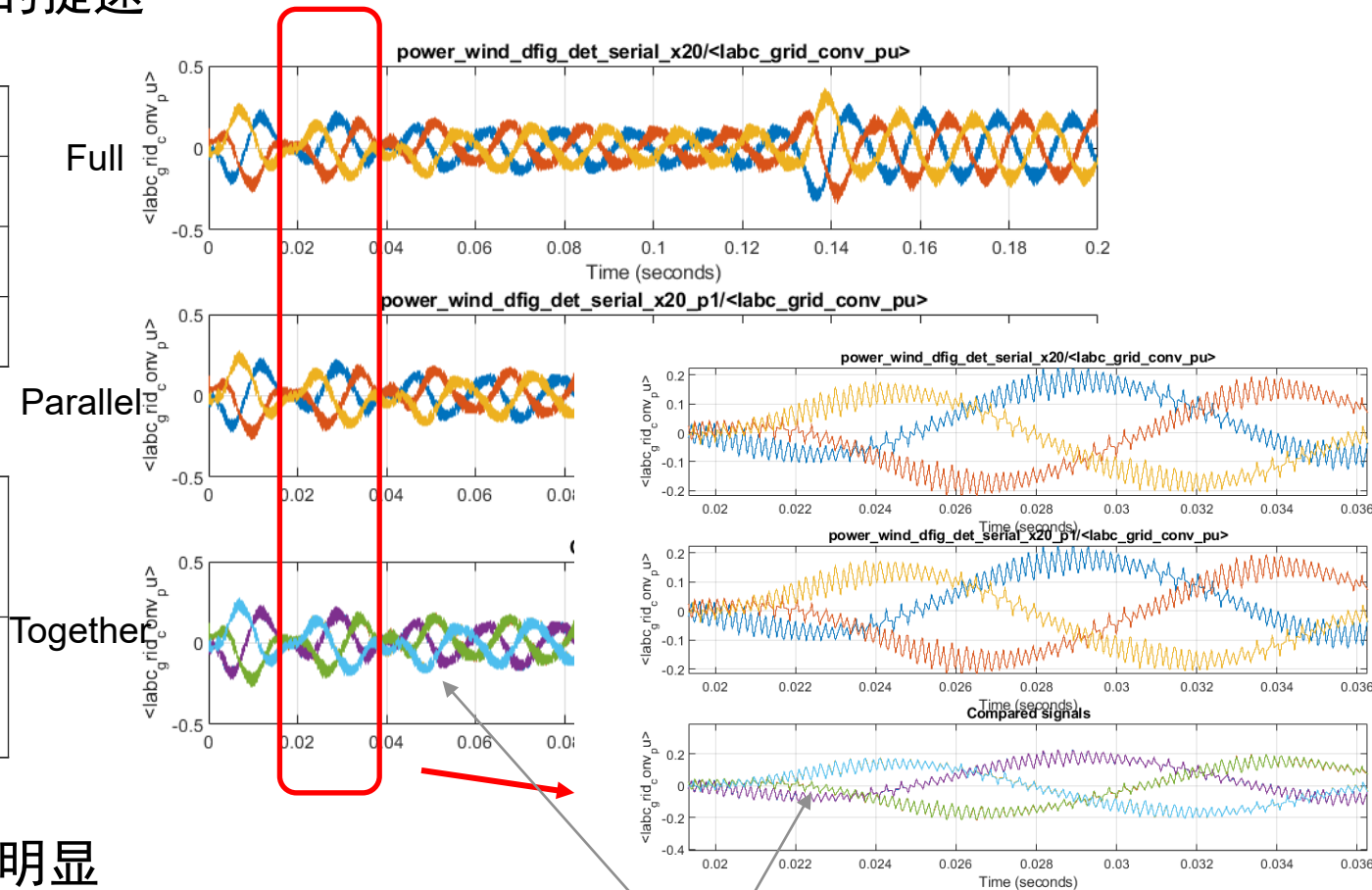
仿真耗时

近七倍的提速



加速模型提升效果更明显

低穿暂态仿真结果比较 Full model and Parallel Models



仿真结果一致

总结

- 仿真速度优化
 - Solver Profiler – 步长查看
 - Simulink Profiler – 模型仿真时间统计
 - Performance Advisor – 模型性能检查
 - 加速模式 – 利用代码进行仿真加速
- 并行仿真
 - 物理模型解耦降低仿真复杂度与模型拆分
 - PSIO 实现模型建虚拟连接
 - Parallel Computing 实现并行仿真任务执行

MATLAB EXPO

Thank you



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