

2012 Hyundai Sonata 8.5kW 270V BISG – NCAT Test Report

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**NCAT – National Center for Advanced Technology**

*National Vehicle and Fuel Emissions Laboratory* – *Office of Transportation and Air Quality*

*U.S. Environmental Protection Agency*

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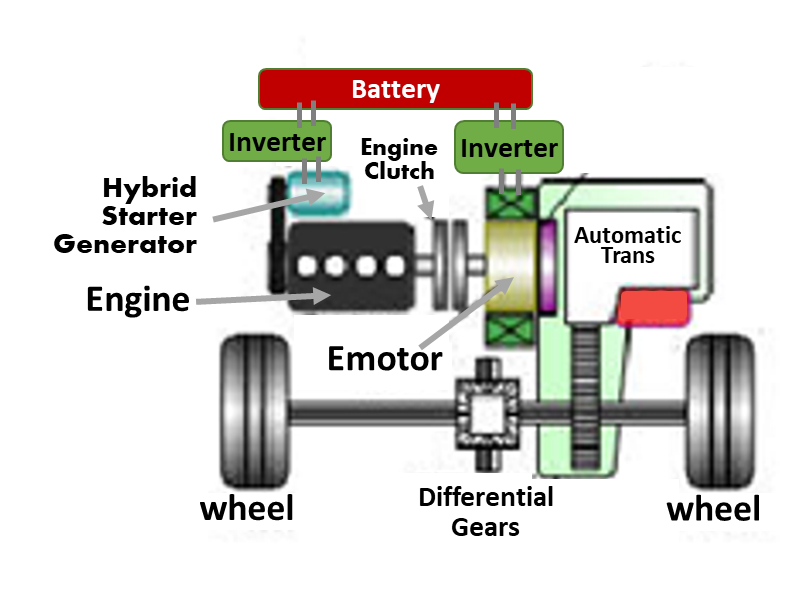
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# Background

The National Center for Advanced Technology (NCAT), part of EPA’s National Vehicle and Fuel Emissions Laboratory (NVFEL), assesses the effectiveness of advanced vehicles, engines, electric motors (emotors), batteries, and transmissions. As part of this work, NCAT benchmarks automotive components and compares the results with benchmarking data from other publicly available sources like published technical papers and programs run by national laboratories and universities. Benchmarking data is then used in EPA’s ALPHA (Advanced Light-Duty Powertrain & Hybrid Analysis) model to estimate greenhouse gas (GHG) emissions. ALPHA is a physics-based, forward-looking, full vehicle model, capable of simulating various vehicle types and powertrain technologies, including electrified technologies.

This test report summarizes the origin and methodology used to create a combined belt integrated starter generator (inverter, emotor and belt) efficiency map from benchmarking data collected from the main inverter, emotor and drive belt from a 2012 Hyundai Sonata hybrid shown in Figure 1. Throughout this report and data package the term “BISG”, a four-letter acronym internally developed by NCAT, designates the component map contains a combination of the “belt integrated starter generator” data.



**Figure 1.** 2012 Hyundai Sonata Hybrid Component Diagram

(a Parallel Hybrid System with the Emotor in the P2 Position)

The data used to create the map originated from research performed by the U.S. Department of Energy’s (DOE) under a cooperative research effort known as the FreedomCAR Partnership. The component testing for this program was conducted by Oak Ridge National Laboratory’s (ORNL) Power Electronics and Electric Machinery Research Center (PEEMRC), a broad-based research center for power electronics and electric machinery (emotor) development. ORNL’s test report and the associated data are included in this *2012 Hyundai Sonata 8.5kW 270V BISG – Test Data Package*.

ORNL presented a summary of their component testing of the 2012 Hyundai Sonata Hybrid Starter Generator (HSG) at the 2013 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting held in Washington, D.C. This presentation is included for reference in the data package: *3d- Benchmarking State-of-the-Art Technologies Presentation by ORNL May 2013.pdf [1].* The information was also included in DOE’s FY 2013 Annual Progress Report for the Advanced Power Electronics and Electric Motors Program included for reference in the data package: *3e- FY2013 DOE Annual Progress Report Advanced Power Electronics and Electric Motors Program.pdf [2]*.

In addition, ORNL staff provided a detailed description of their overall electric motor test program, design, and packaging characteristic assessment, and inverter & emotor performance/efficiency benchmarking testing conducted on a 2010 Toyota Prius. This report is also included as reference in the data package: *3f- Evaluation of the 2010 Toyota Prius Hybrid Synergy Drive System by ORNL March 2011.pdf [3].*

**Purpose of Test**

The purpose of the ORNL testing was to benchmark the efficiency of the Hybrid Starter Generator (HSG) including the main drive emotor, inverter, and belt designed for the 2012 Hyundai Sonata hybrid. Results of ORNL’s study were used by NCAT to create an ALPHA emachine input map to be used to simulate the operation of various hybrid vehicles, including this Hyundai Sonata.

# Test Article

The 2012 Hyundai Sonata hybrid contains an electric motor paired with an inverter powered by a 270-volt lithium polymer battery. The published specifications for the Hybrid Starter Generator (HSG) are listed as 43 Nm, 8.5kW, and 15,750 rpm. Table 1 lists the key specifications of the vehicle and the test article. Figure 2 provides an image of the HSG rotor and Figure 3 shows an image of the HSG stator. The ALPHA component name for this test article is *“2012 Hyundai Sonata 8.5kW 270V BISG”.*

**Table 1.** Vehicle and Test Article Specifications

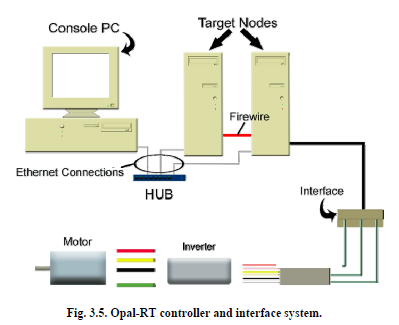
|  |  |
| --- | --- |
| Model Year | 2012 |
| Manufacturer | Hyundai |
| Model | Sonata HSG |
| Curb Weight | 3457 lbs |
| Emotor Type | PMSM |
| Emotor Max Power | 30 kW |
| Emotor Peak Torque | 205 Nm |
| Emotor Max Rated Speed | 6000 rpm |
| Battery Type | Lithium polymer |
| Nominal Battery Voltage | 270 Volts |
| Transmission | 6-speed automatic |
| Tire Size | P205/65R16 |
| Engine Description | 2.4-liter 4-cylinder |
| Engine Power | 124 kW |
| Engine + Emotor Power | 154 kW |

|  |  |
| --- | --- |
|  |  |
| **Figure 2**. 2012 Hyundai Sonata HSG Rotor | **Figure 3**. 2012 Hyundai Sonata HSG Stator |

# Test Methodology

The emotor and inverter were tested using ORNL’s OPAL test setup outlined in Figure 4. A complete description of ONRL’s hardware, interface, data acquisition and setup are described in Section 3 of *3f- Evaluation of the 2010 Toyota Prius Hybrid Synergy Drive System by ORNL March 2011.pdf [3].* While the report describes the setup used to test the emotor and inverter from a Toyota Prius,ORNL used a similar setup to test the 2012 Hyundai Sonata combined belt integrated starter generator (inverter, emotor and belt).

ORNL states in their report that *“ORNL’s dynamometer test cell and Opal-RT-based speed and current feedback controller were adapted to provide the torque needed at each reference speed. Thus, as the applied torque from the dynamometer was varied manually, the controller regulated the torque producing current appropriately*.” To map the inverter-emotor,ORNL bypassed Hyundai’s inverter controller using its custom OPAL-RT system to control the output of Hyundai’s inverter to drive Hyundai’s emotor. This process is used to determine efficiency across the entire torque-speed range of the emotor.

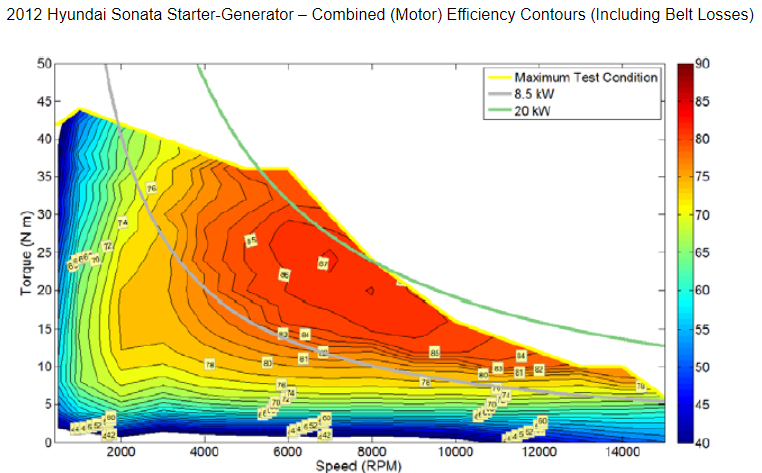


**Figure 4**. ORNL’s Opal-RT Controller and Interface System

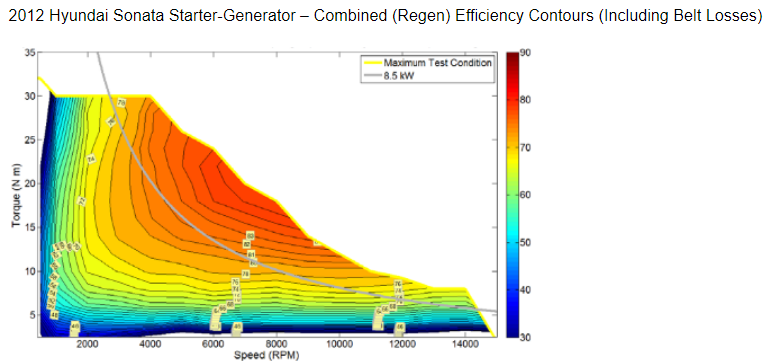
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# Data Set

After installation in ORNL’s dynamometer cell, data were collected at stable emotor/inverter operation conditions over a range of steady state torque and speed operating points for the efficiency contour map of the combined emotor and inverter assembly. These mapping points include a series of regularly spaced points. Figures 5 and 6 below show the contour map images of this data as included in *3d- Benchmarking State-of-the-Art Technologies Presentation by ORNL May 2013.pdf [1]* and *3e- FY2013 DOE Annual Progress Report Advanced Power Electronics and Electric Motors Program.pdf [2]*.



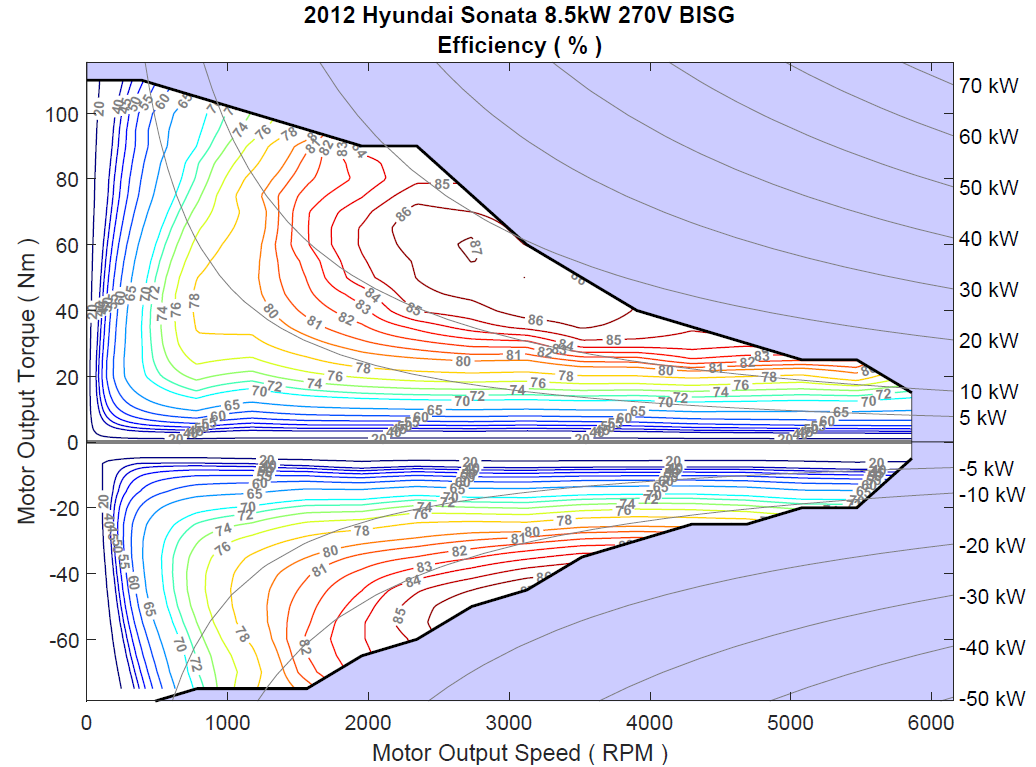
**Figure 5.** ORNL’s Motoring Efficiency Contour Map of the Starter-Generator Including Belt Losses from the 2012 Hyundai Sonata HSG



**Figure 6.** ORNL’s Regen Efficiency Contour Map of the Starter-Generator Including Belt Losses from the 2012 Hyundai Sonata HSG

# Results

Using the ORNL efficiency data and the process described in the html file: *3a- 2012 Hyundai Sonata 8.5kW 270V BISG - ALPHA Generation Process.html,* NCAT created the ALPHA input map shown in Figure 7 which is also available as a standalone image in the complete data package.

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**Figure 7.** NCAT’s ALPHA Efficiency Contour Map of the Starter-Generator Assembly from the 2012 Hyundai Sonata BISG

# References

[1] T. A. Burress. (May 14, 2013) “Benchmarking State-of-the-Art Technologies,” presented at 2013 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting, Washington, D.C. Available at [https://www.energy.gov/sites/prod/files/2014/03/f13/ape006\_burress\_2013\_o.pdf](https://gcc02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.energy.gov%2Fsites%2Fprod%2Ffiles%2F2014%2F03%2Ff13%2Fape006_burress_2013_o.pdf&data=05%7C01%7Cbutters.karla%40epa.gov%7Cf0b2cfbcbca2465c137308da6b3e6e25%7C88b378b367484867acf976aacbeca6a7%7C0%7C0%7C637940213120109878%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=YgASmFq34s1GcAKC0tiTt9%2B%2F7yIXtvO5m67VW4rbr6s%3D&reserved=0)

[2] U.S. Department of Energy, Energy Efficiency and Renewable Energy Vehicle Technologies Office. (December 2013) *FY2013 Annual Progress Report for the Advanced Power Electronics and Electric Motors Program.* Document DOE/EE-1040. Available at <https://www.energy.gov/sites/default/files/2014/04/f15/2013_apeem_report.pdf>

[3] T. A. Burress, S. L. Campbell, C. L. Coomer, C. W. Ayers, A. A. Wereszczak, J. P. Cunningham, L. D. Marlino, L. E. Seiber, and H. T. Lin. (March 2011) *Evaluation of the 2010 Toyota Prius Hybrid Synergy Drive System.* Document ORNL/TM-2010/253.  Available at [https://info.ornl.gov/sites/publications/files/pub26762.pdf](https://gcc02.safelinks.protection.outlook.com/?url=https%3A%2F%2Finfo.ornl.gov%2Fsites%2Fpublications%2Ffiles%2Fpub26762.pdf&data=05%7C01%7Cbutters.karla%40epa.gov%7C8660ac99ef71432e6e9f08da6b342cbe%7C88b378b367484867acf976aacbeca6a7%7C0%7C0%7C637940169074854949%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=9ALPvMxT%2BCFO8GHwNmy93x43lfPNzC5QFEYFrLT4fug%3D&reserved=0).