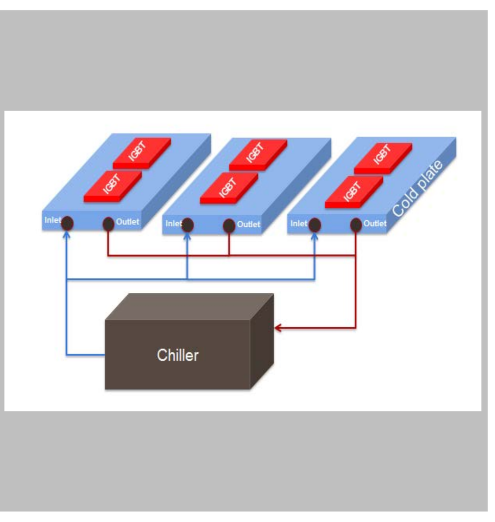

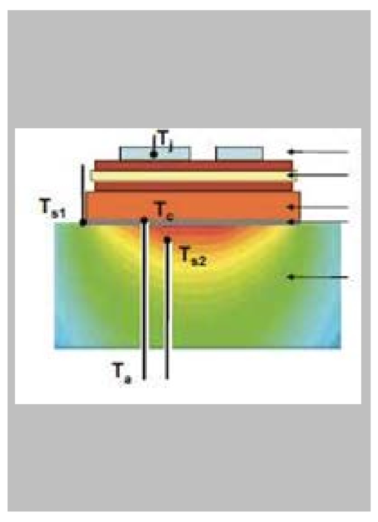

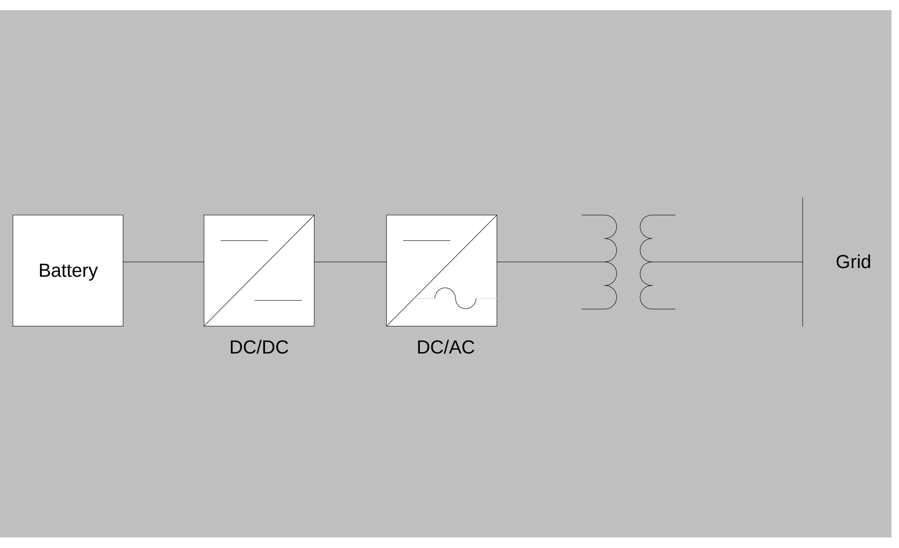

Exceptional service in the national interest

Multi-Objective Optimization for Power Electronics used in Grid-Tied Energy Storage Systems

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MOTIVATION

Increased penetration of renewables and greater loads will present an opportunity for wide spread use of energy storage systems (ESS) in the future. ESS needs to be cost effective, reliable, and safe, among other objectives. Demonstration of multi-objective optimization applied to ESS is needed.

OBJECTIVE

Demonstrate multi-objective optimization using a genetic algorithm for ESS, specifically applied to a DC/AC power electronics inverter for a grid-tied Battery Energy Storage System (BESS). Develop an optimization model which consists of objective functions, decision variables, and a Pareto front of optimal non-dominating solutions.

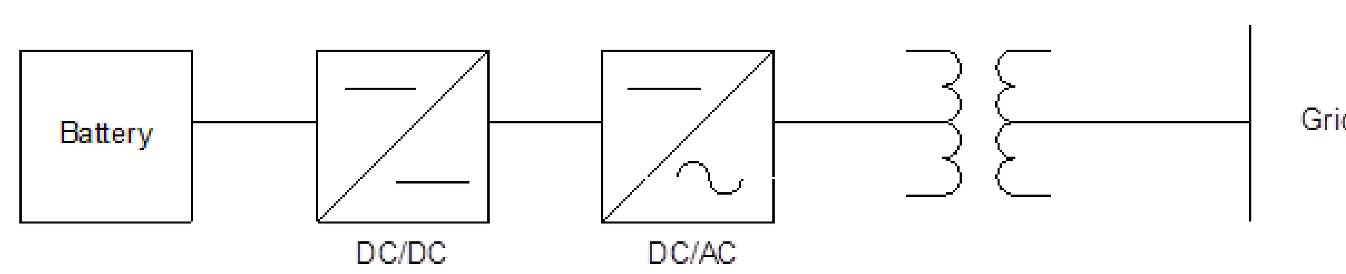

Figure 1. Battery Energy Storage System (BESS)

BACKGROUND

A highly important component of the DC/AC inverter is the semiconductor switch. For this application, the IGBT switch was studied.

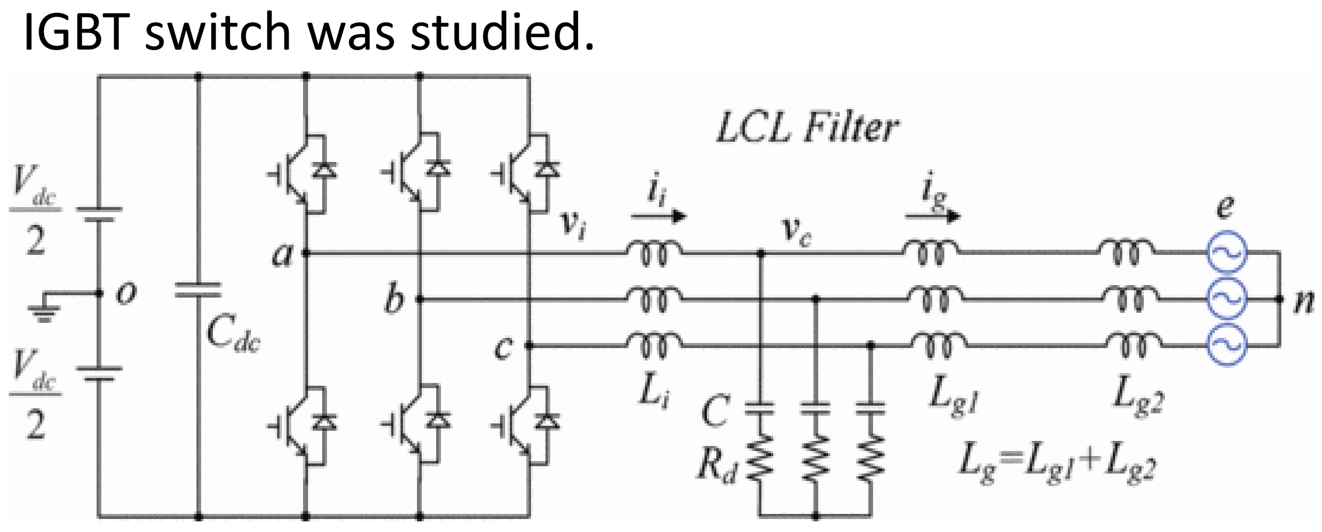

Figure 2. Three-phase DC/AC Inverter, consisting of six switches and an LCL output filter

The genetic algorithm used for multi-objective optimization minimizes two or more objective functions (dependent variables) by coming up with a Pareto set of solutions consisting of the decision variable(s) determined for the problem (independent variable(s)). Two objective functions and two decision variables were determined for this optimization. The two objective functions were failure rate and cost.

ANALYSIS AND RESULTS

IGBT failure rate is a function of Junction Temperature, T_j, which is subsequently impacted by the switching frequency, f_{sw}, and the thermal resistance, R_{sink}.

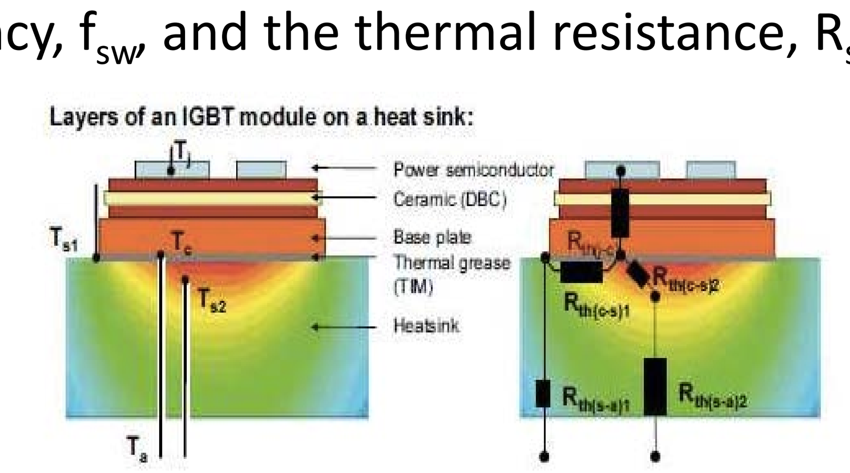

Figure 3. IGBT Module with Thermal Resistances

Failure Rate Equation:

$$Obj\ 1:\ FR = \frac{X^2}{2NH\exp\left(\frac{E_a}{k}\left(\frac{1}{T_{use}} - \frac{1}{T_{stress}}\right)\right)}$$

Where

FR = in number of failures per equivalent device hours,

$T_{use} = T_j$, Use temperature at the junction (deg C + 273) in K

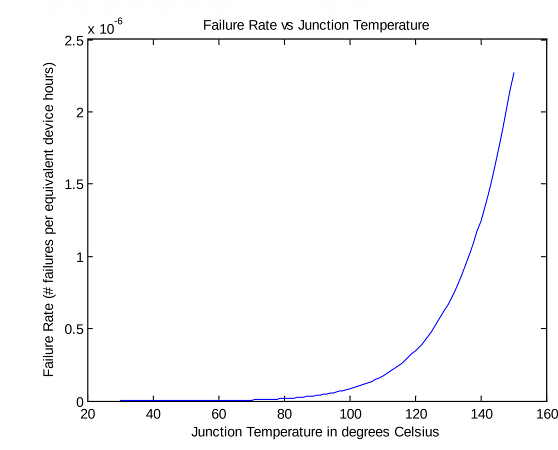

Figure 4. Failure Rate vs. T_j

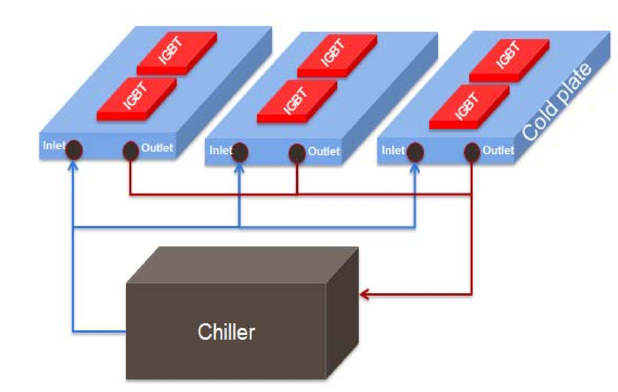

Figure 5. Cooling System

T_j as a function of f_{sw} and R_{sink}:

$$T_j = (R_{jc} + R_{grease} + R_{sink}) * (n_{switch} f_{sw}(E_{on} + E_{off})\left(\frac{1}{1000}\right) + I_{output}V_{CE}) + T_a$$

Where

T_j = Junction Temperature in deg C

f_{sw} = Switching Frequency controlled by PWM

R_{sink} = Heat sink to ambient thermal resistance in deg C/W

Cost Function:

$$Obj\ 2:\ Cost = Cost\ of\ One\ Inductor + Cost\ of\ One\ Cold\ Plate + Cost\ of\ \frac{1}{3}\ of\ the\ Chiller$$

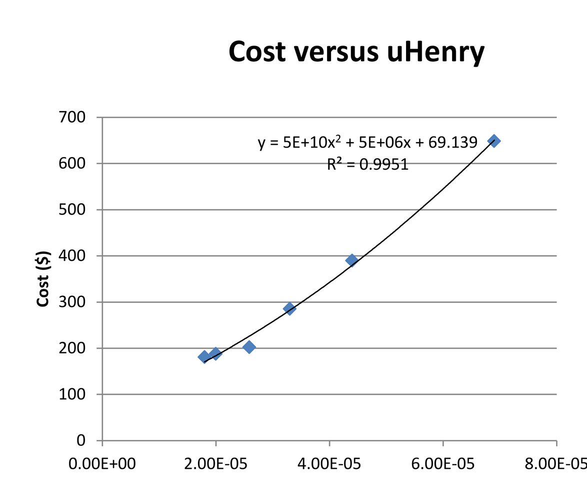

Figure 6. Cost vs. Inductor Size

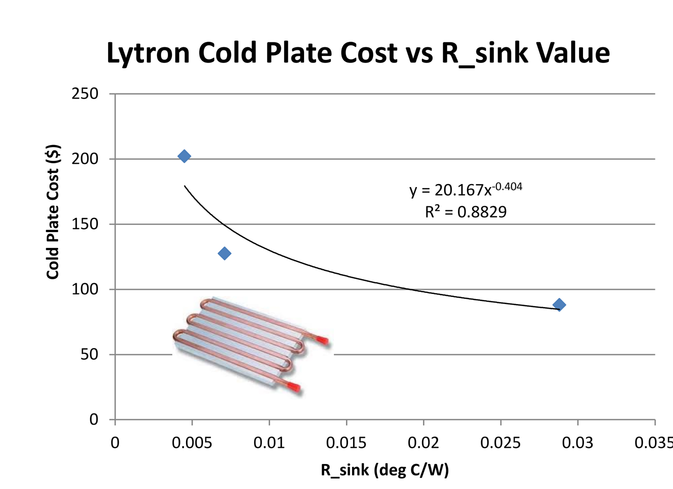

Figure 7. Cost vs. R_{sink} value

The inductor size for the cost function is a function of the switching frequency, f_{sw}. The inductor size affects the ability of the LCL filter to filter harmonics. The R_{sink} value is a characteristic of the cold plate used to cool the IGBT.

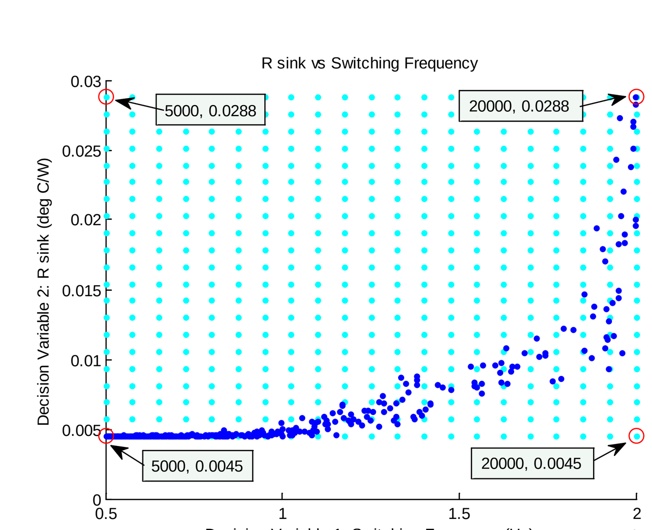

Figure 8. Pareto Set in Decision Variable space

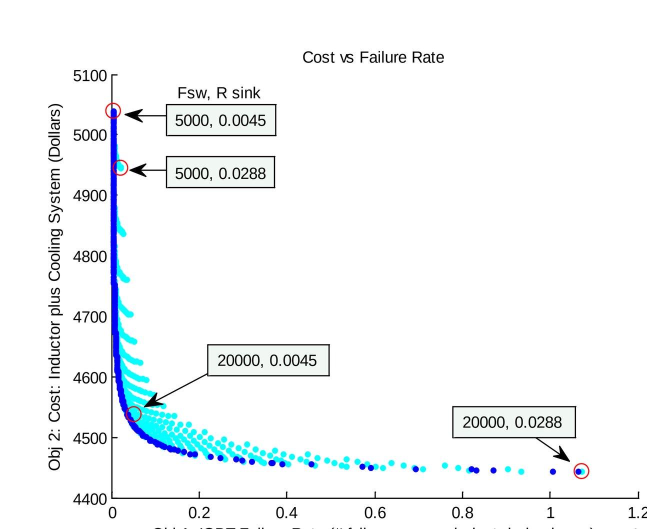

Figure 9. Pareto Set in Objective Function space

Conclusion: Higher switching frequencies are sensitive to cooling (changes in R_{sink})

FUTURE WORK

Incorporate more parts of the inverter in the optimization process. Include BESS battery, DC/DC . Add safety, load management as a objective functions.

ACKNOWEDGMENTS

Dr. Imre Gyuk and the Energy Storage Program in the Office of Electricity Delivery and Energy Reliability

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND No. 2011-XXXXP