Power Electronics

Power electronics is broadly defined as a solid-state energy conversion technology that enables efficient and agile processing and control of electrical power. The key elements of power electronic circuits are: electronic (solid-state) switches and energy storage elements on one side, and control subsystem on the other side.

A switched hybrid system model is given in state space form \( \dot{x}(t) = A x(t) + B u(t) \). The general behavior of a hybrid automaton consists of discrete state transitions and continuous evaluation. HA provide a natural modeling formalism for power electronics.

Definition 1: We define a switched hybrid system to be a 6-tuple \( H = (\Lambda, Q, E, \phi, \Pi, \Omega) \) where: \( Q = \{ q_0, q_1, \ldots, q_n \} \) is set of discrete states, \( A, E \subseteq \mathbb{R}^{n \times n} \) are the continuous state space, \( E \subseteq \mathbb{R}^{n \times n} \) assigns to every discrete state a continuous vector field on \( A, E \subseteq \mathbb{R}^{n \times n} \) as the set of discrete transitions, \( \phi: E \rightarrow [0,1]^n \) assigns each transition \( e \in E \) to a set of guards\( \phi(e) \subseteq \mathbb{R}^n \).

The switched hybrid system model is given in state space form as \( \dot{x}(t) = A(\lambda(t)) x(t) + B(\lambda(t)) u(t) \). The boost converter is a high efficiency DC/DC switching-mode power converter, with an output DC voltage greater than its input DC voltage.

Challenges in Design Automation of Power Electronics

The level of automation in the design, prototyping, verification and testing of power electronics systems is, in many aspects, in the early stages of development. Especially if we compare EDA for power electronics, with for example, with EDA for integrated digital circuit design.

An appropriate design and testing of power electronics systems could potentially reduce overall electricity consumption by more than 30%.

Power electronics enables power flow interface of solar photovoltaic with the grid. It provides an efficient interface between variable wind turbines and the grid that enables maximum wind power conversion. It allows for power flow control between an electric vehicle motor and battery. It enables power grid dynamic stabilization.

An adequate design, testing, and validation of power electronics systems could potentially reduce overall electricity consumption by more than 30%.

Modeling of Power Electronics as Switched Hybrid Automaton

By their very nature, power electronics systems are hybrid systems since they consist of a combination of discrete and continuous features. As such, they are best formalized as hybrid automata (HA). The behavior of a hybrid automaton consists of discrete state transitions and continuous evaluation. HA provide a natural modeling formalism for power electronics.

Definition 2: In this framework we also define a system-mode, denoted \( m(t) \), where \( m \in Q \) to be the operation of the system defined by given state space \( \lambda(t) = A(\lambda(t)) x(t) + B(\lambda(t)) u(t) \) and a given \( E \).

Challenges in Design Automation of Power Electronics

The current design process exhibits several limitations that can be summarized as follows:

1. Non-unified design platforms for power and control part.
2. Use of time-consuming off-line simulations (time-domain) that partially cover the parameter and design space.
3. Lack of well defined design process interfaces.
4. Lack of rapid prototyping tools for both hardware and control subsystems.
5. Inadequate real-time control system verification and testing, and poor test coverage against faults, parameter variations, etc.
6. Lack of rapid prototyping tools for both hardware and control part.

An appropriate design and testing of power systems has to incorporate high-fidelity, real-time emulation of power electronics in Hardware-in-the-Loop (HIL) configurations. HIL permits proper validation of operational scenarios by interfacing the platform with other physical systems needed to model the environment.

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Our Proposed Design Flow for Power Electronics

Our design framework uses new abstractions and modeling approaches that allows various power electronics applications to be expressed under one general hybrid formulation. It is a software/hardware co-design environment. The software tool model tools electrical circuits as switched hybrid automata analyzes, synthesizes, and maps them onto a novel parallel computing hardware.

Circuit models are expressed as switched hybrid models which can be executed on a single hardware platform.

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Prototype of the proposed architecture on an FPGA is deployed and tested in a physical environment. It enables a high-fidelity (with 1s latency and emulation time-step), safe, and fully realistic testing and validation of detailed aspects of power electronics systems.