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MPPT Control of Photovoltaic Systems Using Statechart With Abstraction and Its Comparison With Fuzzy Logic

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ABSTRACT

Maximum power point tracking (MPPT) control is an indispensable aspect of photovoltaic (PV) systems. Many MPPT techniques including a few based on soft computing have been employed earlier. The soft-computing techniques include fuzzy-FSMs (finite state machines), which are integration of fuzzy logic (FL) into states or transitions of FSMs which are used for control and modeling of real-time systems. However, FSMs pose certain disadvantages as compared to its advanced variant called 'statecharts'. In this work, statecharts with abstraction layers are proposed for MPPT control of PV system. An abstract-statechart MPPT (ASM) controller is developed and is verified with PV system using co-simulation. A C++ based FL MPPT program is also developed, which is independent of any predefined and simulation-only functions. A conceptual estimation of execution time of such a FL MPPT program is presented and compared with the execution times delivered by proposed ASM controller. It can be observed that the ASM controller gives accurate, fast tracking speeds, along with the advantage of abstraction.

KEYWORDS

Abstraction, FSM, Fuzzy Logic, LabVIEW FPGA, MPPT, Photovoltaic, Statechart

INTRODUCTION

Soft computing techniques for maximum power point tracking (MPPT) of photovoltaic (PV) systems have been already used to achieve better performance of the systems (Amit et al., 2019; Hanane & Elhassan, 2018). These techniques include fuzzy logic control, genetic algorithms, probabilistic computing, etc (Amit et al., 2019; Mohmed et al., 2020). These techniques have also been used in conjunction with another effective tool for implementing real time control and modeling, which is the Finite State Machine (FSM). FSMs have been used as Fuzzy-FSMs(Hamzaoui et al., 2020a; Hamzaoui et al., 2020b; Mohmed et al., 2020; Reyneri, 1997; Speranskii, 2015), Genetic-FSM synthesis(Ali et al., 2004; Bereza et al., 2013), probabilistic-FSM(Li & Tan, 2019), etc. Hence, FSMs have hence established a significant hand-shake with soft computing techniques in various applications.

However, FSMs have certain limitations due to lack of abstraction in representing a complex system with many states which results in explosion of states(Harel, 1987; Lahari et al., 2019; Mierlo & Vangheluwe, 2019). This could pose a problem in efficiently integrating the FSM with a

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soft-computing technique. To overcome this limitation of FSM, in this work, an extension of FSM, 'statechart' is presented for MPPT control of a PV system. The statechart is developed for an FPGA target and is modeled with abstraction in this work.

Statecharts, that can represent, model and also implement control of complex systems using states, transitions and actions codes (Harel, 1987; Mierlo & Vangheluwe, 2019), have unique features as explained further. Statecharts allow for 'abstraction' in their models, which is to have number of layers of states instead of a flat set of states as in FSMs. This abstraction or layering of states provides compact, simpler and flexible modeling possible. Statecharts also have feature of history, which is, their abstract or layered states can be modeled to have 'memory' of the last inner state that it was active in, before the higher-layered state is left. Also, statecharts method of communication is 'broadcast-communication' through which every state, layered or non-layered, can be communicated of an event occurring at any other state of the system at the same time as the event occurred and an apt control action can thus be achieved. These traits of abstraction, history, 'sensing' of an event by all states at same time (broadcast-communication)(Harel, 1987) make statecharts highly flexible, reliable and apt for systems that require 'softness' instead of 'crisp' methodology in their implementation and modeling. Hence, statecharts can be integrated seamlessly with other soft-computing techniques, as an alternative to FSMs being integrated in fuzzy-FSMs, genetic-FSM synthesis, probabilistic-FSM, etc.

For this reason, abstract-statecharts are proposed in this work, developed for achieving MPPT control of a photovoltaic system, with fast tracking speeds. The statechart is developed for an FPGA as a target and performance of the PV system is verified with the abstract-statechart MPPT(ASM) controller so-developed.

Also developed in this work is a C++ based fuzzy logic(FL) program for achieving MPPT control, so as to present a brief comparative aspect with the developed ASM controller. However, unlike conventional methods of fuzzy logic models using MATLAB fuzzy inference system(FIS) or MATLAB code(Aymen et al., 2018), a C++ based fuzzy-MPPT program is developed and result verified from an online compiler is presented. Implementing FL developed using FIS into hardware digital controllers require specific hardware interfacing modules(Aymen et al., 2018; Sana & Anis, 2018) with MATLAB. Else, they are to be verified in pure simulation which cannot be completely reliable as far as the real-time execution times of the FL are considered. FL developed based on MATLAB code uses pre-defined fuzzy-based function provided by the software which cannot be directly utilized to be deployed into physical embedded targets. When verified using pure simulation, this method also does not accurately provide the execution times of the FL control. To make approximate estimation of execution times of the FL possible even in simulation, FL programs developed around textual languages that can be used to program embedded targets are to be used, which are C and C++, as they can be easily converted into assembly language programs(Sibigtroth, 1996) and based on the target digital controller and its machine cycle frequencies(Atmel, n.d.), the execution times of the FL program can be estimated. Hence, in this work, the FL developed for comparison of its estimated execution time with that of the ASM controller, is based on C++. This requires that every stage in FL development (namely defining fuzzy variables, membership functions, fuzzy rules, aggregation/defuzzification) is to be programmed as the embedded targets do not have pre-defined fuzzy functions like MATLAB simulation provides. In this work, development of code for each part of FL in a textual language without pre-defined fuzzy libraries is discussed and presented. The execution time of FL code so-developed is approximately estimated and compared with the results obtained from the proposed abstract-statechart MPPT(ASM) controller.

Background

Statecharts and fuzzy logic can have a good integration with each other, as already indicated by successful applications of fuzzy-FSMs (Mohmed et al., 2020; Speranskii, 2015). However, the hand-shake between fuzzy logic and statecharts would be more efficient due to the duality between the two and also because statecharts address the limitations posed by FSMs(Harel, 1987). It can be understood