ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–20

Available online at www.sciencedirect.com

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Event driven Hybrid Bond Graph for Hybrid Renewable Energy Systems part I: Modelling and operating mode management

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ARTICLE INFO

Article history:
Received 23 May 2017
Received in revised form
5 October 2017
Accepted 12 October 2017
Available online xxx

Keywords:
Hybrid renewable energy systems
Green hydrogen
Operating mode management
Green hydrogen
Hybrid bond graph

ABSTRACT

This paper proposes a generic tool named Event-Driven Hybrid Bond Graph (EDHBG). The main objective of the proposed approach is the use only one global model to represent all the distinct dynamics resulting from the switching behaviour of the system. Compared with classical approaches such as the hybrid automata, the Operating Mode Management (OMM) is more effective due to the separation between the continuous dynamics, represented by the BG continuous state, and the discrete state governed by a classical automaton. The innovative interest in this work is that it allows for a non-expert user to perform modelling without expressing the algebraic equations of the system and regardless of its hybrid aspect. The modelling approach is applied to Hybrid Renewable Energy Systems (HRES) represented by a multi-sources system which composed of Solar Photovoltaic Panels (PV) and Wind Turbine (WT) coupled with an EL to produce green hydrogen stored and when needed feeding a Fuel Cell (FC). A reduced size experimental HRES is presented to demonstrate the effectiveness of the proposed technique.

Introduction

General context

Today carbon based electricity and transport represent the major contributors in inducing the global warming [1]. Due to the fast growing energy demand, this energy-pollution dilemma requires more than ever an energy transition toward clean energy sources. Solar and wind energies, as the most abundant energy sources, represent sustainable clean alternatives to confront the increasing climate change and pollution problem. However, regardless of their long-term sustainability, these sources are not permanently available nor stable. They depend on the random state of the weather, the day-night and the seasonal cycles. The fact that the majority of renewable sources does not provide a stable power over a day time basis emphasizes the need of a power storage unit. Moreover, due to the seasonal intermittency between the solar and the wind energy, combining both sources contributes in increasing the overall seasonal reliability of the system. As a local storage unit, different techniques are used to store the surplus of the produced energy. Among them, generally, batteries are the most widely used. As an interesting energy carrier, hydrogen, if used as a parallel energy storage, represents a suitable solution for long term and large-

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https://doi.org/10.1016/j.ijhydene.2017.10.144
0360-3199/

Please cite this article in press as: Abdallah I, et al., Event driven Hybrid Bond Graph for Hybrid Renewable Energy Systems part I: Modelling and operating mode management, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.10.144

Abbreviations

BG	Bond Graph
CJV	Controlled Junctions Vector
DES	Discrete Event System
EDHBG	Event-Driven Hybrid Bond Graph
EL	Electrolyser
FC	Fuel Cell
HA	Hybrid Automaton
HBG	Hybrid Bond Graph
HDS	Hybrid Dynamical Systems
HPN	Hybrid Petri Net
HRES	Hybrid Renewable Energy Systems
MPN	Mixed Petri Net
Mppt	Maximum Power Point Tracking
OM	Operating Mode
OMM	Operating Mode Management
PMG	Permanent Magnet Generator
PV	Solar Photovoltaic Panels
SSE	State-Space Equations
STG	Standard Temperature and Irradiation
WT	Wind Turbine

scale storage. The produced hydrogen by electrolysis can be stored to then regenerate electricity, mechanical work or to be used in various chemical applications. These hydrogen applications, illustrated by [Fig. 1], show how hydrogen can play a major key role in controlling the pollution on many levels. Providing a solution for both major pollution sources: production of electricity and transportation, hydrogen can lower the dependency on carbon-based fuel in both contexts electrical [2,3] and combustion engine powered vehicles [4,5]. It also can be used as power source in stationary applications. As a raw product, it can be used in many chemical process. Methanation for example is one interesting chemical application where greenhouse gases: carbon oxides (CO_2, CO) and hydrogen are used to produce methane.

Furthermore, compared to other electrochemical power storage options such as batteries, Hydrogen presents higher energy mass-density, faster storage recharge (refill), more stable storage with less self-discharge, etc. The fact that Hydrogen represents long-term stable storage, the management of the excess of the produced power can be unrestricted and flexible regarding the storage time. Storage techniques that rely on only Battery-based storage units suffer from loss in the storage capacity and present environmental inconvenient concerning the after-service disposal. Combined with multiple renewable energy sources, the EL and the FC represent interesting energy storage solution. They couple electricity, as the most common energy form, with hydrogen, as zero-emission flexible energy storage.

From energetic point of view, such combined systems are defined as HRES.

Hybrid Renewable Energy Systems (HRES)

From dynamical point of view, some units (such as the wind turbine, electrolyser, fuel cell and utility grid ...) present different operating modes. Indeed, they need to be disconnected and reconnected to the power system according to different operating conditions and protection measures.

Having such interconnection between different varieties of sources and storage units, where each or some can be connected and disconnected, engenders a dual discrete-continuous dynamical behaviour. Mathematically, this indicates that the system dynamical behaviour, usually described by the State Space Equations (SSE), evolves continuously with respect to the time and discontinuously according to the Operating Mode (OM) (switching state). Therefore, for each OM a different set of SSE is needed to represent the dynamical behaviour. In control and automatic engineering, this class of systems is identified as Hybrid Dynamical Systems (HDS) or more precisely switching systems. Because of this dual dynamical aspect, such systems are very difficult to interpret as fully continuous nor as only discrete.

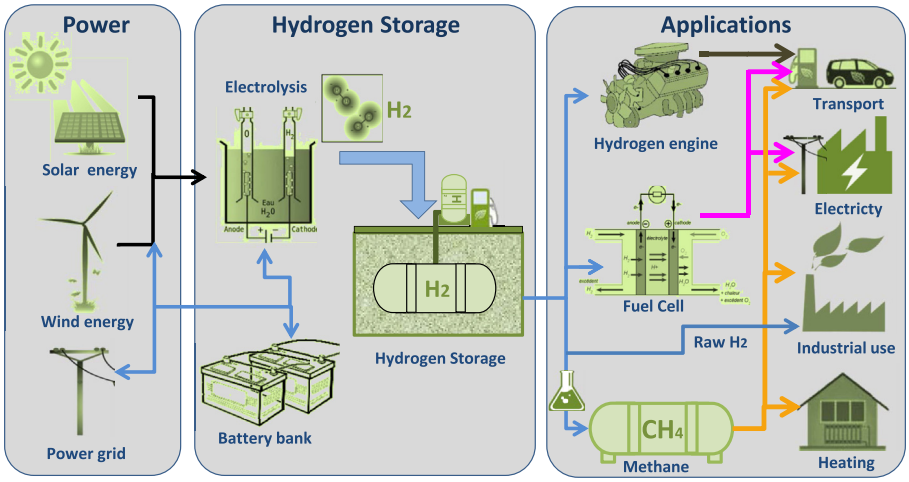

Fig. 1 – Green hydrogen applications: variety and flexibility. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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