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IFAC-PapersOnLine 49-25 (2016) 523–528

Proposal of an Intelligent, Predictive Fuzzy Controller for Off-Grid Devices

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Abstract: Off-grid electrical devices, such as autonomous lamps, can operate without being connected to the power grid thanks to integrated renewable-source based energy generators and storage facilities. However, they may not be able to fulfill all of the user's requirements in unfavourable conditions. Controllers currently used in off-grid devices use simplistic algorithms and strategies. This paper presents a proposal of an intelligent, fuzzy logic-based controller for off-grid devices with prediction and planning capabilities. Artificial neural networks of various types are used for prediction of generator performance, monitoring of component performance and detection of events such as partial malfunction. Fuzzy logic is used for to facilitate the definition of rules reflecting the user's preferences, and to define the internal strategies of the controller. The predicted behaviour of the power-related components is used to select the operating mode which fulfils the prioritised user's requirements to the maximum extent, while minimizing the chance of running out of power.

Keywords: off-grid device, artificial intelligence, neural networks, fuzzy control, prediction

1. INTRODUCTION

Off-grid devices are electrical appliances which operate without being connected to the power network. To accomplish that, they require one or more power generator (usually based on renewable sources) and some form of energy storage. These devices are normally used in locations not equipped with power infrastructure and can serve many purposes: lighting, ventilation and air conditioning, distribution of goods, monitoring, etc.

An example of such device – an autonomous lamp – is presented in Fig. 1. Besides the visible luminaire and photovoltaic panel, the device is also equipped with a battery, usually placed underground.

Currently used off-grid devices use simplistic control rules and algorithms to determine the "optimal" mode of operation. For instance, an off-grid lamp will typically switch itself on at sunset and back off at sunrise when these events are detected using the integrated PV panel. Weather forecast, which is the primary determinant of generator performance, is not taken into account, and no prediction methods are used.

2. PROBLEM STATEMENT

An off-grid device relies entirely on the energy produced by the integrated generators and stored in the battery. Therefore, in unfavourable conditions, the device may run out of energy before the next chance to generate more. Installation of an oversized battery is not feasible due to economic and technical reasons: the battery would increase

Fig. 1. An off-grid lamp. (Source: Wichary Technic)

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.12.077

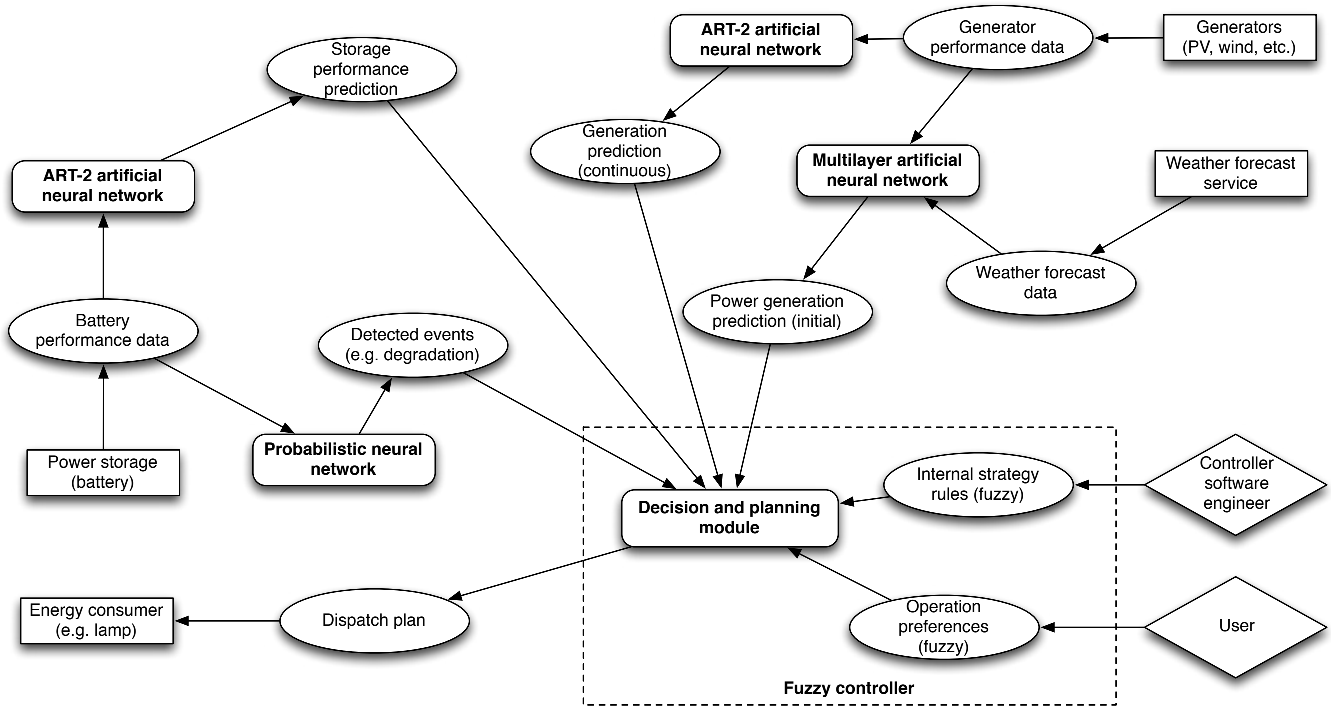

Fig. 2. Functional scheme of the proposed controller; arrows denote data or control flow.

the total price of the device, and for most of the time it would be operated in a flat charge cycle, which would shorten its life. In other words, an off-grid device may not always be able to fulfil *all* of its user's requirements.

Therefore, it is crucial for the user to assign priorities to their preferences. For example, the user may state that "the lamp *should* be on from sunset till sunrise, but *must* not be dimmed down when the recorded vehicle traffic level is high."

Moreover, the performance of generator devices (PV panels, wind turbines) and batteries (charge and health characteristics) may vary from device to device and change over time. Therefore, it is crucial to monitor the performance of all components in a device and to employ algorithms which predict the performance of generators and batteries given the recorded operational data and external information, such as the weather forecast.

The following sections present a concept of an intelligent controller for off-grid devices and provide a survey of methods which can used to implement it.

3. OVERVIEW OF THE PROPOSED SOLUTION

The proposed controller should allow for user-friendly definition of preferred operation modes and make use of prediction algorithms to determine the possible performance of power generation and storage facilities.

The general scheme of the controller is presented in Fig. 2.

Operation of the device is determined by the amount of available energy which, in turn, is determined mostly by the weather conditions. Operational data of the generators is constantly gathered, analysed and used as training data for prediction modules based on artificial neural networks. [1]

Artificial neural networks are also used to predict the characteristics of the battery, which changes in time and depends on external factors, such as ambient temperature.

Fuzzy logic can enhance this solution in several ways. Firstly, it is a friendly, natural way of expressing the user's preferences with regard to operation of the device. Instead of defining strict ranges of sensor data (e.g. traffic levels) and output modes (e.g. lighting intensity), the user may use concepts such as "light", "dark", "high", "low", "moderate", etc. Secondly, the results of operation data analytics and prediction can be expressed as fuzzy variables, which may reduce the amount of data which needs to be processed by the controller. This aspect is important, as it will often be implemented using a resource-constrained, embedded device.

Moreover, fuzzy logic may easily be integrated into control planning algorithms such as the ones described by Wojnicki (2016).

The following two sections present selected methods in the two aforementioned categories and discuss their adaptability and usefulness for the proposed off-grid device controller. A more concrete proposal for integration of these methods is presented in Section 6.

[1] If not enough training data is available (e.g. in new deployments), simulation methods may be used to predict performance based purely on device characteristics, as described by Ernst (2016).