



Energy Resources Intelligent Management using on line real-time simulation: A decision support tool for sustainable manufacturing



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HIGHLIGHTS

- A new way to manage the self production of energy from RES in manufacturing industry.
- Optimization in terms of both energy costs and environmental impact (CO₂ emissions).
- The use of on-line real-time Discrete Event Simulation to manage the stochasticity.
- The energy production plan is dynamically suited to weather and manufacturing needs.
- The test case presented highlights the effectiveness of the proposed methodology.

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ABSTRACT

At a historic time when the eco-sustainability of industrial manufacturing is considered one of the cornerstones of relations between people and the environment, the use of energy from Renewable Energy Sources (RES) has become a fundamental element of this new vision. After years of vain attempts to hammer out an agreement to significantly reduce CO₂ emissions produced by the burning of fossil fuels, a binding global accord was finally reached (Paris December 2015 - New York April 2016).

As we know, however, some of the most commonly-used RES, such as solar or wind, present the problem of discontinuity in energy production due to the variability of weather and climatic conditions. For this reason, the authors thought it appropriate to study a new methodology capable of marrying industrial users' instantaneous need for energy with the production capacity of Renewable Energy Sources, supplemented, when necessary, by energy created through self-production and possibly acquired from third-party suppliers. All of this in order to minimize CO₂ emissions and company energy costs.

Given the massive presence of stochastic and sometimes aleatory elements, for the proposed energy management model we have used both Monte Carlo simulation and on-line real-time Discrete Event Simulation (DES), as well as appropriate predictive algorithms. A test conducted on a tannery located in southern Italy, equipped with a 700 KWp photovoltaic installation, showed extremely interesting results, both economically and environmentally. In particular the application of the model permitted an annual savings of several hundreds of thousands of euros in energy costs and a comparable parallel reduction of CO₂ emissions. The systematic use of the proposed approach, gradually expanded to other manufacturing sectors, could result in very consistent benefits for the entire industrial system.

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1. Introduction and literary review

Since the early 2000s, the concept of Sustainable Manufacturing has had an increasing presence in the industrial field. To summarize extremely briefly, the principal objective is to establish a rela-

tionship between manufacturing and the environment, with greater attention to protecting the latter.

The idea of sustainability applies and extends to each phase of the industrial manufacturing cycle:

- in product design: possibly making use of recyclable and non-polluting materials;
- in manufacturing: seeking to minimize manufacturing waste and the use of energy from traditional sources and the consequent CO₂ emissions;

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- in distribution: reducing as much as possible ground transportation and the product's carbon footprint.

A significant contribution for sustainability is made by the correct management of energy, particularly electric power. A complete analysis of the importance of energy management in manufacturing has been recently presented in a review article based on 365 papers published from 1995 to 2015. The authors investigated six main lines of research related to energy management in this specific context of study [1]. The term “sustainable”, when applied to the use of energy, is evoked, on the one hand, in the search for less consumption per unit produced, and on the other hand, in the growing use of self-production through Renewable Energy Sources (RES). “Cleaner Energy for cleaner production” was the leit motiv of the 17th conference “Process Integration, Modelling and Optimization for Energy Saving and Pollution Reduction-PRESS” which aim was to share with the scientific community ideas and technologies that can be used in the real world. Modelling, Simulation and Optimization were the main topics of this conference [2]. However, in the face of the above, there is a significant problem caused by randomness in the volumes of production generated by most RES, whose behavior is predictable only with margins of uncertainty, which are not always trivial. This makes their use problematic in cases where there are continuous consumption demands according to pre-set schedules, as with industrial applications. Until effective storage systems become available, it will always be necessary to supplement discontinuous RES sources (sun and wind, for example) with traditional sources to ensure continuity in energy supply during the hours in which RES production is absent. A focus on sustainability therefore requires the identification of an integrated management model that privileges, where possible, the self-production of RES and minimization of the use of traditional sources. Some authors consider the storage of energy supplied by RES, that at times exceed the demand, as a way to reduce the mismatch between the supplied energy and the forecasted production, due to forecasting errors, using the Stochastic Approximation Average technique [3]. Other authors attempted to reduce both the energy consumption costs and CO₂ emission by predicting the energy consumption using predictive methodologies as the Methods-Energy Measurement [4].

After an accurate analysis of the scientific literature, the authors note the lack of methodologies with the objectives presented in this paper, that is, an energy management strategy that allows the simultaneous minimization of CO₂ emissions and costs of production, acting, under stochastic conditions, both from the perspective of energy consumption and production by RES and traditional sources.

In fact, some authors approach the problem only from the perspective of predicting energy demand [5–8] while many others only from the perspective of predicting energy availability from RES sources [9–15]. With regard to the use of DES for the purpose of energy savings and optimization of consumption, the authors found some interesting contributions. Ghani et al. use DES for the real-time evaluation of energy demand in the automotive industry in the redesigning phase of the manufacturing process in order to optimize the sizing of the production line with a view toward energy savings [16].

Kouki et al. developed a framework called ERDES (Energy-Related Discrete Event Simulation), which again uses DES for the purpose of predicting future energy consumption at various times of the day in order to test different scheduling scenarios for manufacturing activities and, consequently, minimizing energy costs [17].

Both contributions, though offering interesting insights, approach the problem only from the perspective of optimization of consumption and not production of RES energy.

Some authors have recently proposed a real time method of energy control in manufacturing systems. Their aim is to have an increase of production of energy by RES on site. They act in stochastic regime using also DES but their methodology, according to the authors themselves, shall be improved because there is no fit with the paradigm of Lean Manufacturing [18].

In order to obtain effective and efficient management of RES, predictive models for both the industrial energy demand and the production capacity of RES (in relation to the predicted weather and climatic patterns) are required. The objective of the proposed study is to provide Energy Managers in manufacturing environments with a support tool that, using the potentialities of Discrete Event Simulation (both on-line and on-line real-time) and the Monte Carlo simulation, supplemented by a special predictive algorithm, allows optimization of the energy supplying mix (self-production from renewable and not renewable sources and/or purchase on the electricity market).

Through this approach, as we will see below, both the economic impact, in terms of energy procurement costs, and the environmental impact, expressed in terms of reduction of CO₂ emissions, can be significantly reduced. This is in full accord both with the Sustainable Manufacturing

Compared to the models found in literature the methodology proposed by the authors is able to optimize both the cost of energy and the CO₂ emissions without affecting the scheduling of production. It is the model that fits to the reality on the basis of the changed operating or atmospheric conditions and not vice versa.

Another important feature is, as demonstrated in the test case described in the paper, the relative ease of application of the proposed methodology. To apply the methodology no specific knowledge on the logic and the statistical techniques underlying the model are required. To manage optimally energy sources is sufficient interpret the results provided by the model. The authors point out that, unlike other studies, the proposed methodology takes into account the self-production through cogenerative microturbine and the purchase or sale of energy produced to the grid (in defect or in excess, respectively), in order to preserve the economic sustainability of the operation.

2. Methods: the ERIM-P and ERIM-RT models

In dealing with the problem of the supplemented and optimal use of energy produced by RES in manufacturing, the authors, taking some DES previous studies [19,20] as a jumping-off point, propose a management approach based on two steps, supported by two respective models called ERIM-P (Energy Resources Intelligent Management-Predictor) and ERIM-RT (Energy Resources Intelligent Management-Real Time).

The purpose of ERIM-P is to develop, 24 h in advance, two types of predictions:

- (1) the hourly electrical energy requirement of the manufacturing plant based on a production plan created for the next day, but keeping in mind the stochastic events present in the system (breakdowns, stoppages, missed appointments, availability of materials, variability of processing and set up times, etc.)
- (2) the quantity of possible self-production of RES energy based on weather predictions for the next day.

By comparing the two hourly profiles (consumption and self-production of RES) it will be possible to determine, as a consequence, the quantity of electrical energy to be self-produced through traditional sources (i.e. microturbines) and, in case, the quantity of electrical energy to be purchased from/sold to the grid.

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