Current consumption monitoring and analysis system for energy management improvement in an industrial complex

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***Abstract*— This paper presents a non-invasive and completely autonomous solution for monitoring the current consumption of an industrial complex. The solution is based on the use of self-harvesting current sensors and wireless data transmission to a local radio network, a gateway from local radio network to LoRa (low power - wide range) as well as to a server that receives and analyses data. Based on this analysis, a power management plan (consumer scheme) can be built for a manufacturing process. The system allows reducing global energy consumption by implementing a dynamic consumer scheme that can accommodate to one or more energy providers.**

***Keywords*— Current consumption monitoring, self harvesting, LoRa communication, data fusion**

I. Introduction

Modern industrial quality standards tend to regulate aspects of the impact of production activity on the environment and the creation of the so-called green industry. Among other things, attention is paid to increasing efficiency in electricity consumption. This paper presents a flexible solution for monitoring power consumption for different industrial equipment, analyzing the evolution of consumption over a certain period and determining the optimal scheme of consumers for an industrial process. There are several challenges that raise a mobile monitoring solution. The first is the measurement method. For easy installation, the method of measuring power consumption must be a non-invasive one. There are several solutions including [1] where a precise measurement technique of current consumption is presented by capturing the electric field. The second is the power supply of sensors and data transmission equipment. One solution here is the use of self-harvesting sensors which capture the power supply field [2]. Also, low-power data transmission and packet processing solutions are used to reduce transmission time [3].

Along with the power consumption acquisition component, we also have the analysis component to build a power management plan. Analyzes of current consumption for optimization have been carried out in modern research works.

In paper [4] are presented more algorithms for energy consumptions: Teaching & Learning based Optimization (TLBO) and Shuffled Frog Leaping (SFL). The workpaper present an analysis using real life cases from industrial complex. The conclusion is that by reducing energy consumption for some periods in a daily manufacturing process can reduce global cost of energy. The paper [5] proposes a novel hybrid algorithm based on AI tools for simultaneous forecast of energy price and customer demand that uses a set of software processing tools in preprocessing part (events receiving and recording), forecast engine and tuned algorithm. In papers [6] as in [7] is presented a novel concept of cost efficiency-based residential load scheduling framework. The cost efficiency is defined as a ratio between customer's total benefit after consumption of energy and the total electricity payment during a certain period (one day). In last paper, it is developed a cost-efficient scheduling algorithm for the demand-side's day-ahead bidding process based on a fractional programming approach. The proposed scheduling algorithm can effectively reflect and affect customer's consumption behavior and achieve the optimal cost-efficient energy consumption profile. A review about "demand response" (DR) concept, about the systems where is applicable and the challenges which it involves is presented in [8]. In short, DR is about to manage the required demand to match the available energy resources without adding new generation capacity.

Our solution in this paper includes a hardware component designed to monitor power consumption at industrial plant level, and a software component that takes data about current consumption at plant level, conducts an analysis and proposes industrial process scheduling to reduce of energy consumption.

A secondary objective of the analysis and scheduling tool is that it offers the possibility of efficient management of electricity sources by adding at certain times suppliers of energy from renewable sources such as photovoltaic or wind power.

The elements of innovation brought by our system compared to other similar systems (commercial or proposed in the works) are the following:

- The presence of a portable power consumption monitoring hardware solution that is easy to install on the industrial power supply cables: our proposed solution involves the use of clamp-meters current sensors that read electrical current by capturing the electric field around the insulated conductor. This ensures a very easy installation of the monitoring solution anywhere in the electricity supply network.
- The energy autonomy of the hardware solution and the wireless data communication in a local radio network. Thus, the number of power and data transmission cables is 0 - they will no longer be present in the plant infrastructure. At the same time, maintenance work on the components is not required.
- Use of new analysis tools based on CEP (Complex Event Processing) engine: real-time analysis and batch analysis for industrial equipment consumption. It is also allowed to enter rules. They aim at reducing current consumption without affecting the production process. As a result, the system will issue an industrial process scheduling to reduce the cost of global energy.
- Design an intelligent scheduling engine which uses the set of rules and is based on genetic algorithms. The genetic algorithm is a suitable multi-criterion optimization solution.

The following section describes our monitoring and analysis system. Next, the analysis engine, an important component of the proposed system, will be presented. Section 4 is dedicated to presenting the results obtained from the use of our solution on an electronic system for printed board circuits consisting of the following components: wiring printer, component stand, oven and automatic testing stand. The paper ends with Section 5 where conclusions and future directions are presented.

II. Presentation of the System

Figure 1 shows a block diagram of the system. As we have seen, the system has two main components: a hardware component for current monitoring: acquiring current from the conductor, transmitting information to the gateway and from there further to the server; and a software component that takes over the data transmitted by the hardware component, analyzes them, passes them through an edited rule engine, through an intelligent scheduling engine that ultimately results in a work plan.

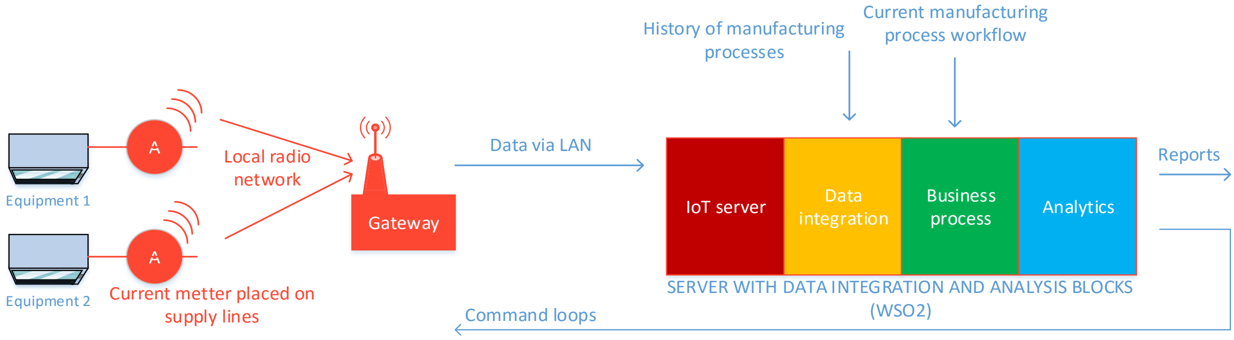

Fig. 1. System block diagram

To acquire the current and transmit it to a radio network, we use Pressac's clamp-meter which are based on the EnOcean circuit which has integrated: the current converter, the analogue digital conversion and the radio data transmission. The system has the following features:

- Acquisition of current consumption by clamp-meter sensors, placed around the insulated power conductor (so it does not require any intervention at the system). The current for our system ranges from 2 to 600A and the accuracy is +/- 1A.
- Transmission of acquired data (current consumption) to a local wireless network in the 928 MHz band. A local radio network can contain up to 15 equipment. The coverage area is about 20 m. The transmission rate is 30 seconds.

The data from the local radio network is taken over by a transmission system made by us based on the Rasberry PI integrated computer. It has a gateway connected to the local radio network, take data and transmits it to USB. Data is encapsulated and transmitted via a LoRa interface (866MHz) to the server. The characteristics of the transmission system are as follows:

- Allows connection of three gateways to receive local radio network data - so it can handle up to 45 devices.
- The system allows the storage of packets of data from local radio networks for 10 minutes.
- The system can transmit data via the LoRa network (coverage 20 kilometers) to the server.

From the LoRa (LAN) network, data is taken over by the server. The server station has a USB gateway that allows LoRa packets to be downloaded. The server application receives the data on the USB (USB receiver), stores them for batch analysis, integrates them with the data from the history of other industrial processes, takes the data on the current process and inserts them into the analysis module. The result is the development of scheduling reports (which reach the management department, quality etc) or even drive commands to equipment.

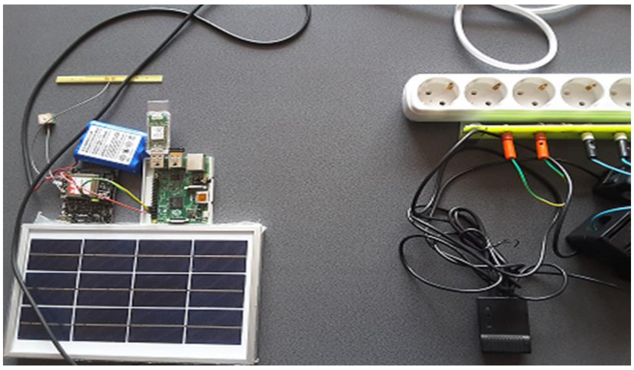

Fig. 2. A picture with our system: right clamps meters and transceiver, left transmission system (RaspberryPI)

III. EVENT MANAGEMENT AND ANALYSIS SERVER

An important component of the system is the server application that handles event capture, storage, and intelligent analysis. The server consists of two modules:

- The Complex Event Processing Module (CEP) that takes over data packets from the power consumption acquisition system. Receiving these packages will generate a server-level event. The module also deals with storing incoming data, setting a set of data preprocessing rules (for example, inserting filters, sorting chronological data), and forwarding preprocessed data to the analysis module. There are data stored from previous measurements for the same technological process or data from other technological processes (current or past). Here is also the work plan for the current technological process monitored. All this information will represent inputs for the analysis module.
- The analysis module consists of a multicriteria optimization kernel that has as inputs the data provided on consumption as well as the working plan of a technological process and provides as an output an optimal scheduling taking into account the following parameters: electricity consumption, keeping the succession from the production work plan by reducing the waiting time between operations and reducing the total time allocated to the technological process, also taking into account the scheduling of similar technological processes. So there are three major criteria that need to be taken into account in determining optimal scheduling: consumption, work plan and time.

For the CEP side, the WSO2 DAS server is used. It allows:

- Building a "receiver" responsible for downloading HTTP data packets. Can handle multiple HTTP requests for packet data reception.
- Building a "data stream" - data stream that is received or processed. These data are data extracted from the receiver and can be stored in a database for further processing.
- Building a event processor that specifies certain preprocessing rules - introduces data filtering or sorting.
- Build a publisher where output data is passed to other modules or to client reporting applications.

The figure below represents the event processing flow built for our solution.

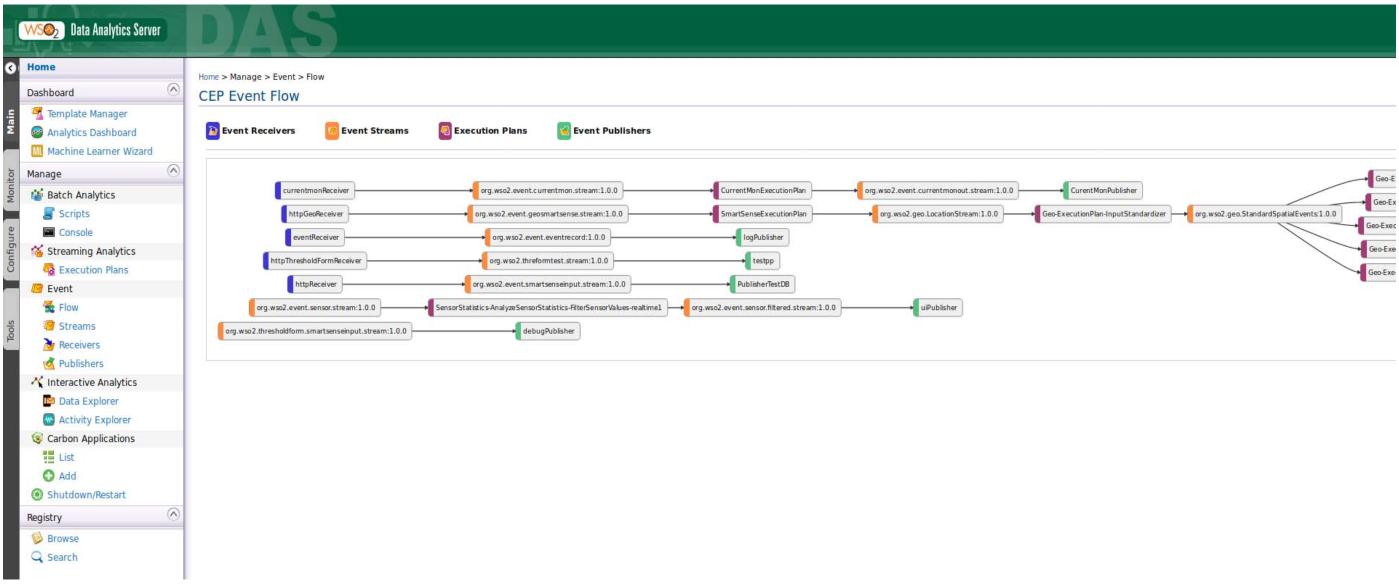

Fig. 3. Event flow of our monitoring and analysis solution (capture from WSO2DAS management portal)

For the analysis part, an intelligent search engine for the optimal solution based on genetic algorithm is used. A structure of the chromosome is presented in figure 4. The chromosome is the potential solution that the genetic algorithm delivers. In our case, the chromosome is a sequence that represents the steps in the proposed production process – a scheduling. Each step has a number (according to the workflow), current consumption (read by the acquisition system), previous consumption and idle time before starting the step. A flowchart of the algorithm is shown in Figure 5

Step number	Current consumption	History current consumption	Idle time
Step number	Current consumption	History current consumption	Idle time

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Fig. 4. Chromosome structure

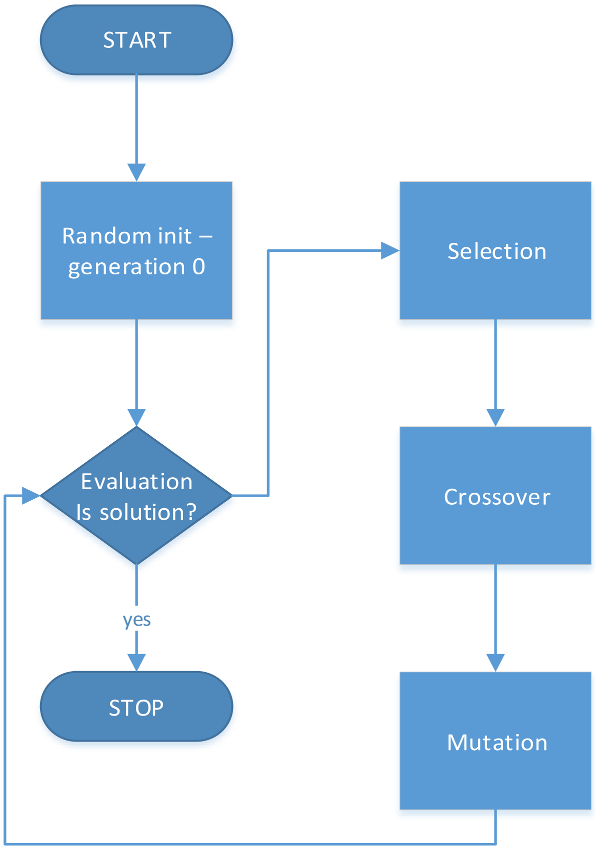


Fig. 5. Genetic algorithm flowchart

IV. System Testing

For experimentation, a process of production of printed board electronic circuits was used in the laboratory of electronic circuits and electronic wiring. The production of a set of 10 electronic circuits was followed. The two equipment that are involved in the production stream and which lead to higher consumption are the wiring printer and the oven. An operating regime is shown in the figure 6 a and b.

The cumulative current consumption for the two unplanned operating equipment exceeds the value of 12 A as you can see in the figure 7.

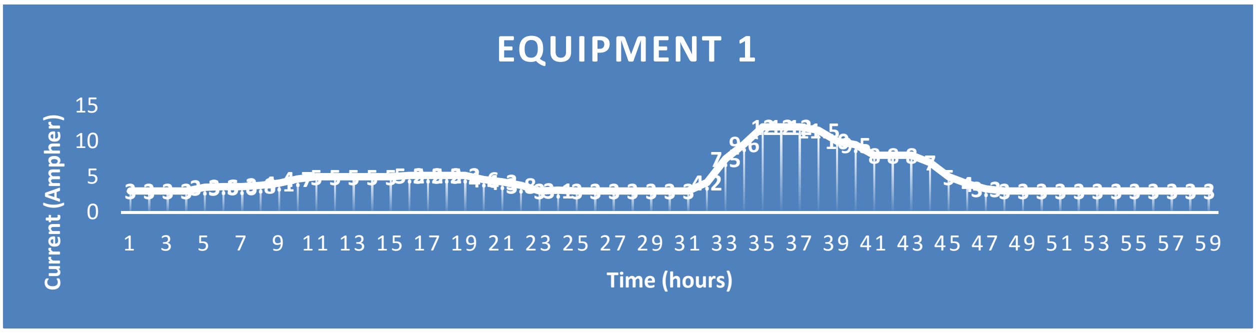
To avoid high current consumption, a genetic algorithm analysis was started. The result was a re-planning of the operating cycle of the equipment 2 to avoid the peak from the 37 – see figure 8.

The algorithm has the following steps: generation 0 where the chromosomes are randomized, the evaluation where each chromosome is tested to see if it is an optimal expected solution, the selection in which parent chromosomes are established: those who will participate in the genetic operators, the crossover that is an operator which combines two parents and results in a offspring chromosome and the mutation that modifies a chromosome.

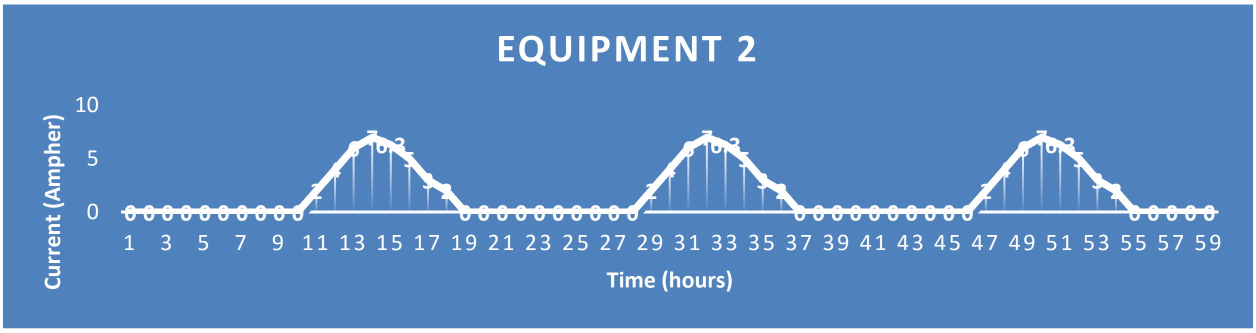
Initialization of generation 0, selection, crossing, and mutation are operations that contain random components: generating initial chromosomes, establishing the chromosome selection interval, the crossing point or the gene that will be changed to the mutation. On the other hand, the evaluation, the selection process or the interchange of the genes at the crossover are deterministic operations. So GA is a pseudo-random optimization solution.

The search domain involves optimization of three parameters that are not correlated.: current consumption, workplan and time. The program should be kept unchanged for the most part. Eventually, processes that do not depend on each other can be considered. Between the current consumption and the production time, a relationship can be established. Thus, two processes can be timed to each other to avoid overlapping current consumption from both. So it can reduce instantaneous current consumption but increase production time.

There can not be a deterministic solution to determine the optimum considering these three uncorrelated parameters. therefore, the pseudo-random bioinspired analysis solution was used.



a) wiring printer consumption



b) Oven consumption

Fig. 6. Consumption in operation mode for equipment

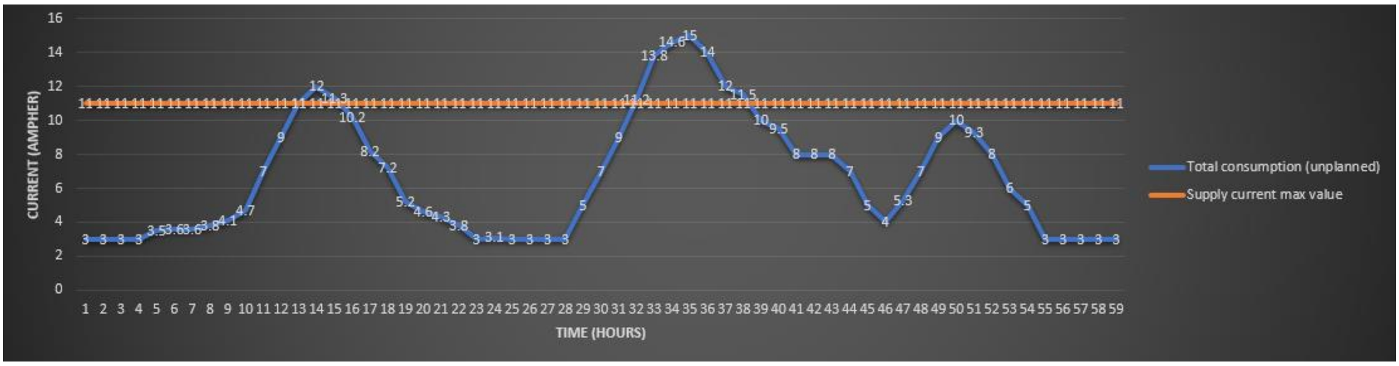


Fig. 7. Evolution of cumulated current consumtion

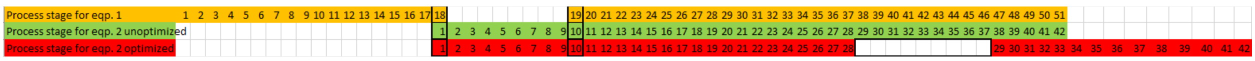


Fig. 8. Un-optimized (green) and optimized (red) scheduling for equipment 2 (oven) after a GA analysis process

V. Conclusions

Our experiments demonstrate the effectiveness of our analysis and scheduling tool. Our solution allows for optimal scheduling that considers both instantaneous power consumption and production time keeping the succession of unchanged production steps (workflow).

From the point of view of production costs, our solution achieves optimal scheduling. The innovation elements are represented by both the flexible, easy to install and maintain solution, but also by the intelligent analysis tool.

Future directions would be to implement the solution proposed in this paper in different industrial processes to prove their reliability in various areas of industry.

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