IoT Energy Retrofit and the Connection of Legacy Machines Inside the Industry 4.0 Concept

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***Abstract*—Industry 4.0 concepts has left the hype behind them to become an industrial reality. Several technological pillars provide support to the so called 4^{th} industrial revolution. Among them are the Digital Twin (based on Cyber-Physical-Systems (CPS)) and the Internet of Things (IoT). Moreover, the interoperability from legacy equipment should be provided to the success of this new factory model. A huge concern is focused on the small and medium enterprises (SME) and their steps toward this new industry. Considering this scenario, this work presents a machine retrofit using an energy measurement industrial sensor, an IoT gateway to provide connectivity to this machine as well as show how the generated data could be sent to the cloud. Once in the cloud the data should feedback the digital energy model in one hand and in another hand be shared with third part partners. In order to manage and build massages in proper communication protocols the Node Red software was used and a mobile application was developed to monitor the energy data in real time.**

I. Introduction

First used at Hanover Fair in 2011, the term Industry 4.0 was coined by Germany to define the new factory model based on the generic concept of CPS. In the beginning, the propositions were faced with suspicious by the industrial community [1]. Once that moment has been left behind, various actions are required to put this industry model into practice.

Diverse customer demands are increasing the need for improved flexibility, adaptability, and transparency of production processes; traditional manufacturing systems must change [2].

These rapid changes have pushed manufacturing companies to adhere to these new concepts. In this scenario of pressure there is a major concern with the insertion of small and medium enterprises (SME), whose investment capacity is limited. A major problem is related to legacy systems and components that are not prepared for a mandatory connectivity and interoperability scenario in Industry 4.0.

Sensors and systems based on the internet of things (IoT) and cloud applications can be used to allow that old and non-compliant equipment should be used within the new Industry 4.0 standards.

Another pillar of industry 4.0 is the virtualization of processes, equipment and components. This virtualization is a first step towards the creation of Digital Twins. Process virtualization, regardless of the virtual model's connection to the physical world, can bring significant productivity gains. In particular, digital manufacturing tools can be used to analyze energy consumption beyond conventional variables such as manufacturing times, for example.

In this work, the concepts presented before are gathered in a practical application for Industry 4.0. The work developed was supported by the teams of two laboratories (Digital Manufacturing Laboratory and IoT Laboratory) of our institution, emphasizing the interdisciplinarity involved in the solution [3]. A number of process virtualization have been developed over time, with a focus on energy consumption in manufacturing systems [4], [5]. On the other hand, considering the physical part of the manufacturing systems, a didactic CNC machine was furnished with the insertion of a power meter and an IoT gateway for the generation of several communication and internet connection protocols. We believe that the solution developed can motivate SMEs to join Industry 4.0.

This paper is organized as follows: section II presents the literature review, section III presents the proposed solution, sction IV presents the results and discussions and finally, section V presents the conclusions and future work.

II. Literature Review

Industry 4.0 is supported by several technological pillars e.g. IoT, Process Virtualization, Augmented Reality, Additive Manufacturing among others. These concepts were widespread and the discussions and implementations are becoming more solid nowadays.

As described in the introduction section a major concern about Industry 4.0 is related to SMEs, specially in developing countries. According to [6], their results show that SMEs do not exploit all the resources for implementing Industry 4.0 and often limit themselves to the adoption of Cloud Computing and the Internet of Things. Considering a Brazilian case, [7] studied the relation of Lean Production (LP) and Industry 4.0 in SMEs. They identified how the association of LP and Industry 4.0 according to different contextual variables (company's size and time of LP implementation) may contribute to improving operational performance in emerging economies.

Virtualization of process is another important approach in Industry 4.0. Moreover, the simulation of manufacturing systems considering the electrical energy approaches are increasing. Considering that manufacturing companies need energy as

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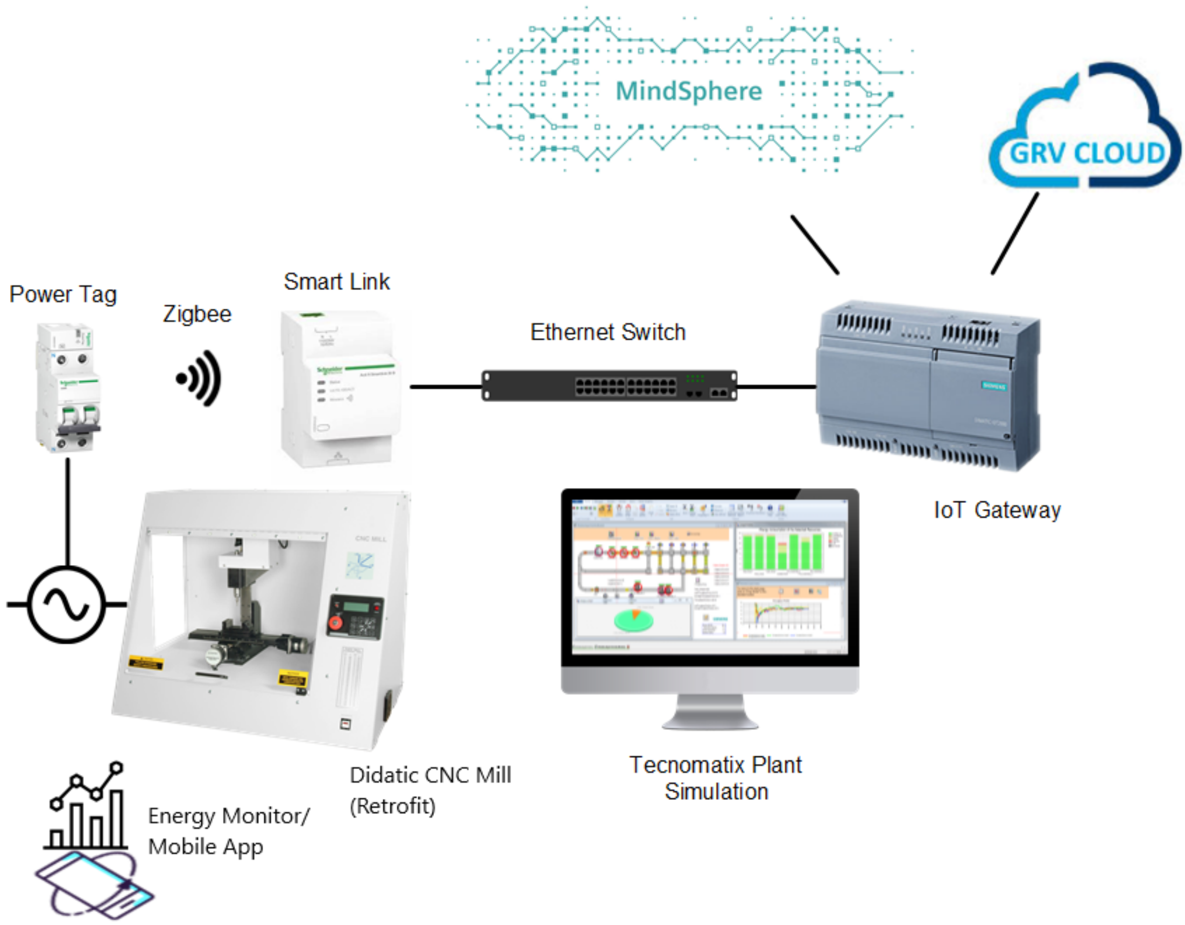

Fig. 1. Block Diagram of the Proposed Solution

a primary element in order to produce goods for the society, limiting production is not a viable option. In this context, facing a scenario increasingly challenging, competitive and regulated, the authors in [8] argue that improving energy efficiency becomes an extremely promising option for manufacturing companies. In a complementary way, according to [9], to improve energy efficiency in manufacturing activities is an inevitable trend for energy conservation, emissions reduction and adherence to sustainability practices. Some good examples of saving energy in manufacturing systems are presented in [10], [11], [12], [13] and [14].

The retrofit [15] of legacy machines is an important issue to be considered, allowing SMEs to adhere to Industry 4.0 at a relatively low cost [16], [17]. Considering the physical world, machines should have their energy parameters measured to provide data to the virtualized model as well as to any partner or costumer. Once power measurements are made, the internet connection and data transmission to a cloud or directly to the partners should be promoted. Considering the connectivity and data transmission, an IoT gateway can be used, as in the work of [18]. The programming of the IoT gateway for the creation of the different communication packets for several protocols can be carried out by the Node Red application, as in the works of [19], [20] and [21].

Another concern into the connected elements in Industry 4.0 is the interoperability [22], [23]. The concept of an administration shell is important to deal with this issue. The concept of an administration shell or an asset administration shell (AAS) is a virtual digital representation of the I4.0 asset that plays a pivotal role in establishing communication among I4.0 Components [2].

III. Proposed Solution

In the following the proposed solution is presented. The solution is based on the virtualization of manufacturing processes using Digital Manufacturing tools, the retrofit of a didactic 20 years old legacy CNC machine using an energy sensor from Schneider Electric, the connection of the machine to the internet using the gateway IoT-2040 from Siemens and the data transmission to the Mindsphere Cloud from Siemens and GRV Software which was responsible to develop a mobile application to monitor the energy data in real time. Figure 1 presents the block diagram of the proposed solution.

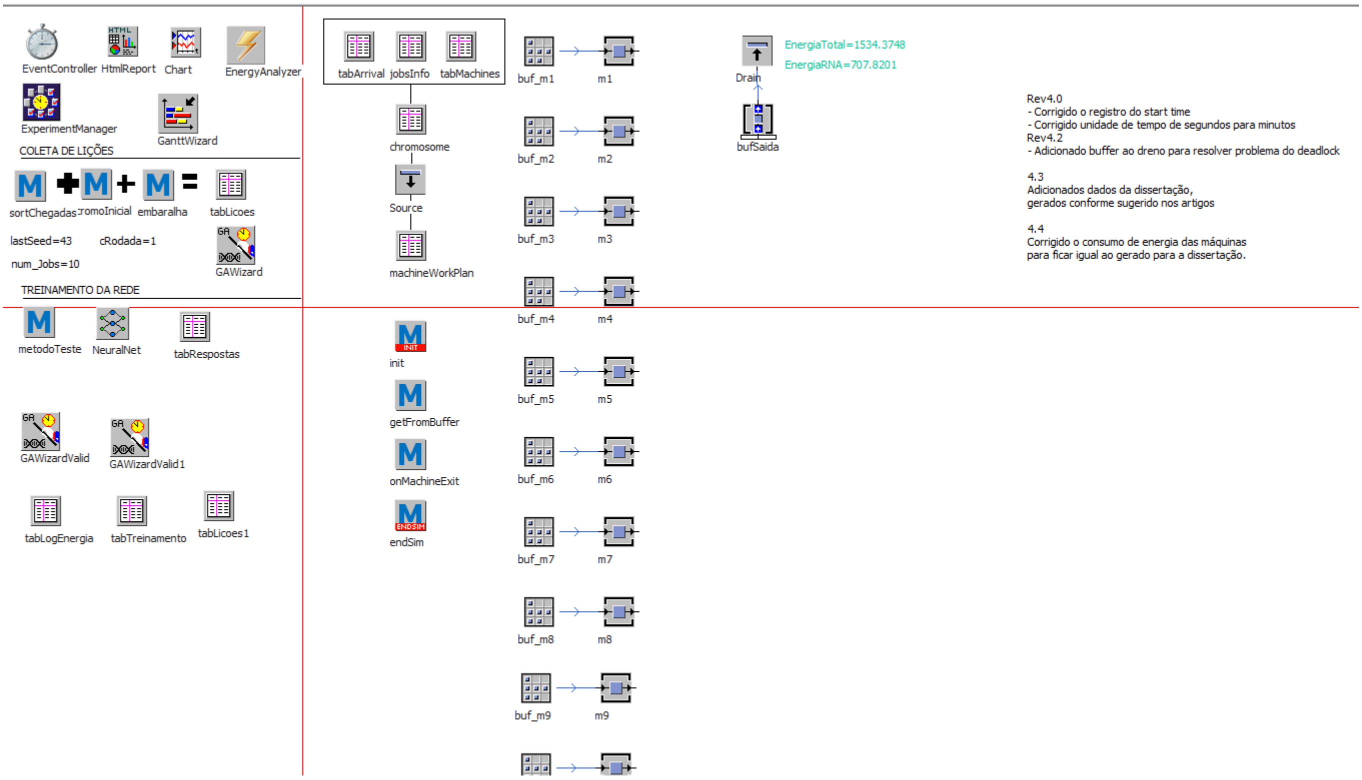

Fig. 2. Simulation model

The details of the solution will be presented in the following.

A. Virtual Energy Model

As described in section I, we have been working with virtualization of processes focused on energy consumption. From a partnership with Siemens, a Digital manufacturing Laboratory was launched in our institution in 2016 [3]. In the simulation of the discrete manufacturing system is possible to provide the consumption of energy in each state of the machine, e.g. "working" and " standby", and the time of the transitions among different states with their energy consumptions. Figure 3 presents the energy parameter window and Figure 2 a simulation model proposed by [4] where a Genetic Algorithm and an Artificial Neural Network were used to estimate the electrical energy consumption in a Jobshop manufacturing system. It is important to highlight that these machine learning packages are available in the same DES software of the Digital Manufacturing. Finally, Figure 4 presents a simulation result, considering the energy consumed per machine in each manufacturing state and Figure 5 presents the total power to perform ten jobs using ten different machines.

B. CNC Mill Energy retrofit - hardware and software

In order to execute the retrofit of a 20 years old CNC mill from LabVolt manufacturer (Figure 6), an energy sensor was installed to measure the amount of energy consumed by any state of the machine operation. Such sensor is called Sensor Tag and it sends data throughout an wireless interface using

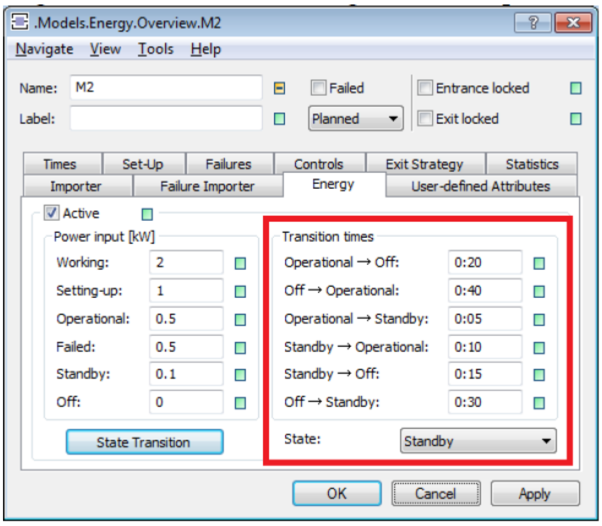

Fig. 3. Energy Window

ZigBee protocol in a 802.15 radio interface to a tag concentrator called Power Link (this name and sensor tag are trademark of Schneider Electric). Figure 7 depicts the equipment used in the retrofit of CNC mill. The concentrator send data from all Sensor Tag by Modbus message protocols under TCP/IP to an IoT gateway (IoT 2040 from Siemens). Both equipment inter-operate through a local Ethernet network.

The IoT gateway collect all data from Power Link and sends

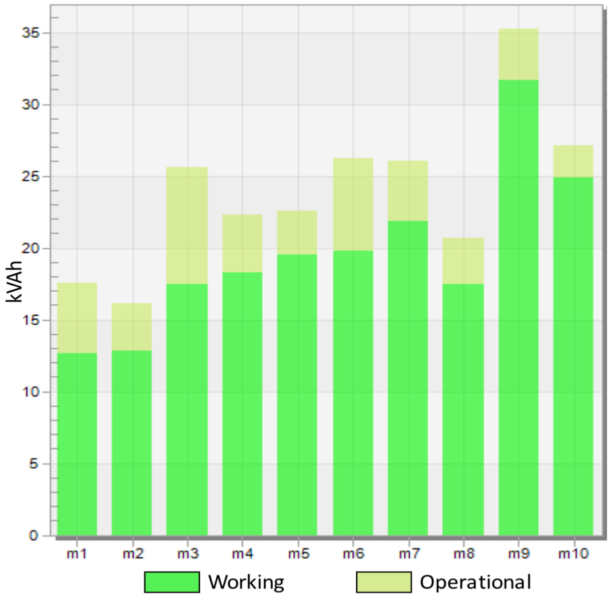

Fig. 4. Energy per machine

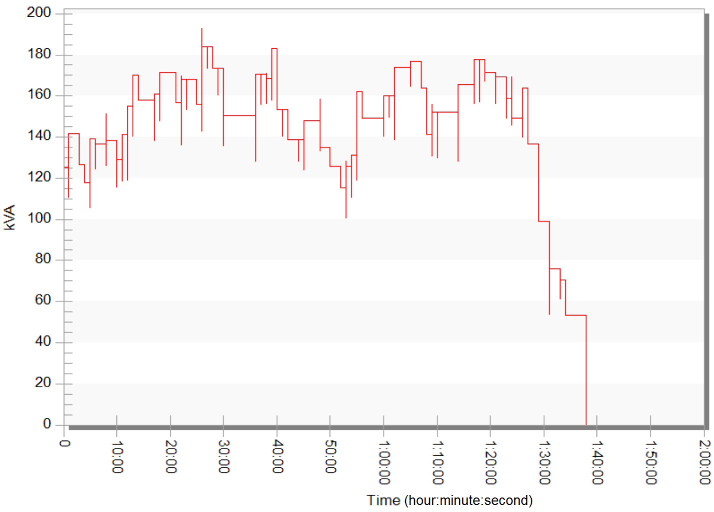

Fig. 5. Total power

data to two cloud infrastructures - Siemens Mindshepre and GRV Software cloud. Each cloud has its own interface and operates with different protocols. The Siemens Mindsphere uses MQTT messages and GRV Software´s cloud uses a HTTP message with a proper payload (similar to a JSON structure). Siemens IoT 2040 software was developed in NodeRed as the basic software structure depicted in Figure 8. The first piece of software composed by the first three lines of blocks is used to create the data structure that will receive sensor data in the Siemens Mindsphere cloud. The second group of blocks is the piece of software that receives data from sensors in Modbus TCP/IP (Electrical Current Measurement (Fig. 8)), converts data to both cloud message formats (two branches after binary data decoding (Fig. 8)) and sends them to each cloud. The green blocks in Figure 8 are just for message echo in NodeRed IDE (Integrated Development Environment) and to log files.

Fig. 6. Original CNC Mill

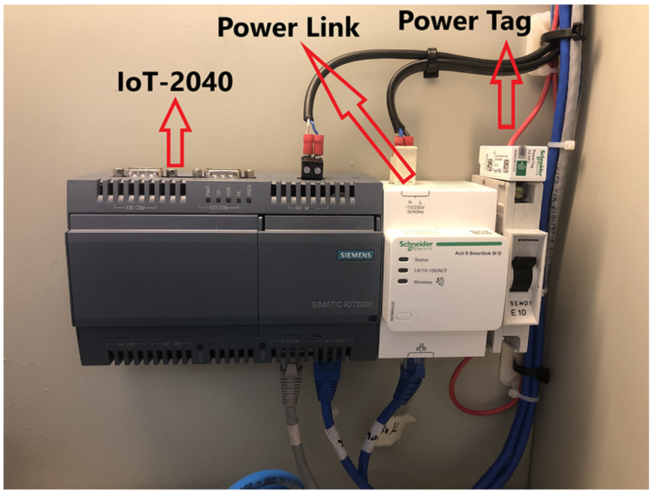

Fig. 7. Energy retrofit

C. Mobile Application

Once the energy data achieved the GRV Software´s Cloud, a mobile application was developed to allow the real time monitoring of the energy parameters of the CNC machine. These data should be monitored in practice by a decision maker, an operator of the machine or by the maintenance staff. Figure 9 presents the mobile screen with some electrical energy information of the machine.

IV. Results and Discussion

The simulation results using the discrete event simulator energy package of the digital manufacturing platform have been used successfully in the evaluation of energy consumption in

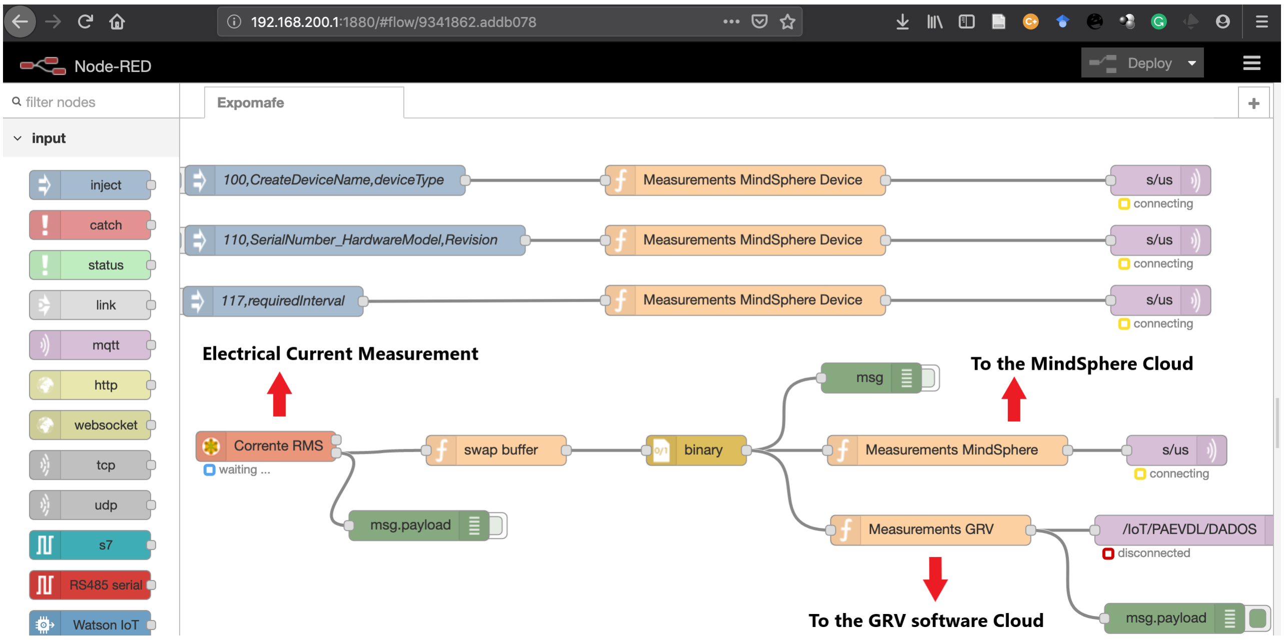

Fig. 8. Block diagram in the Node Red software

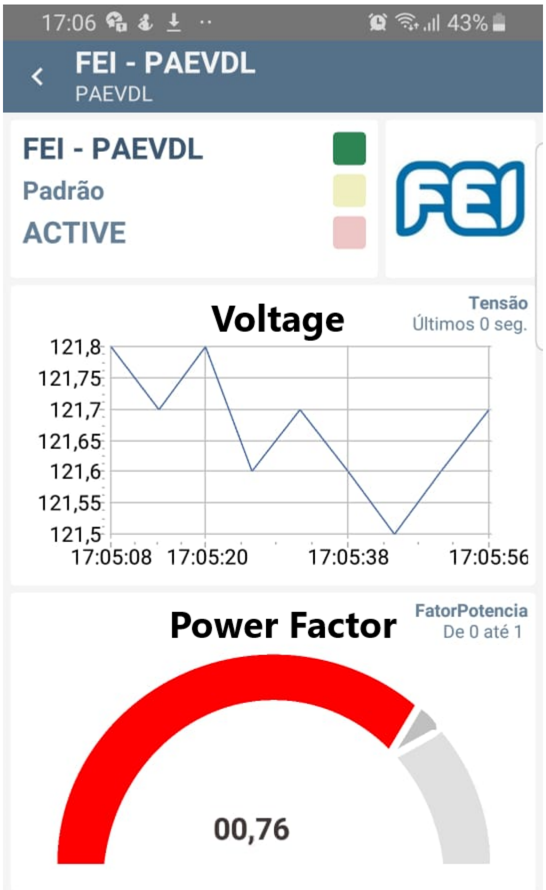

Fig. 9. Mobile energy application screen

manufacturing systems. From this evaluation it is possible to create new scenarios, whose ultimate objective is to improve energy indicators, as presented in [4] and [5]. However, in those works, the power parameters are entered in the software offline. This does not allow the creation of an effective digital twin aimed at energy consumption on individual machines or for an entire manufacturing system.

The transmission of the data to the Mindsphere cloud should allow the feedback of the virtual model with real time manufacturing energy parameters. In this sense, decision-making originated in the virtual model can reach the physical model, such as changing the state of operation of a machine. This will effectively create a digital twin geared towards energy parameters within the concept of closed-loop manufacturing.

The solution developed for the retrofit of the CNC machine has low cost. This encourages SMEs to adhere to this type of approach and consequently go further in the implementation of Industry 4.0.

This work was carried out in partnerships with companies such as Siemens, Schneider Electric and GRV Software that is a Brazilian company. This underscores the importance of collaborative work among companies and universities in the development of solutions focused on Industry 4.0.

V. Conclusions

This article presented the development of a retrofit machine solution for small and medium-sized companies. The development relied on the generation of virtual manufacturing models based on digital manufacturing software in one hand. On the other hand, considering the actual physical system, a solution based on the sensing of electric power parameters of the machine was developed with the data being sent to different cloud platforms. The solution has low cost, reinforcing the possibility that companies with less investment capacity are not excluded from the fourth industrial revolution. As future work, we are developing the connection of the physical and virtual worlds to the effective generation of a digital twin of energy.

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