

Non-invasive system for monitoring of the manufacturing equipment

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Abstract. The automotive industry is one of the most important industries in the world that concerns the economy and the world culture. High demand has resulted in increasing of the pressure on the production lines. In conclusion, it is required more careful in monitoring of the production equipment not only for maintenance but also for staff safety and to increase the quality of production. In this paper, we propose a solution for non-invasive monitoring of the industrial equipment operation by measuring the current consumption on energy supply lines. Thus, it is determined the utilization schedule of the equipment and operation mode. Based on these measurements, it's built an activity report for that equipment, available to the quality management and maintenance team. The solution consists of the current measuring equipment, with self-harvesting capabilities and radio transceiver, and an embedded system which run a server. The current measuring equipment will transmit data about consumption of each energy supply network line where is placed the industrial equipment. So, we have an internal measuring radio network. The embedded system will collect data for the equipment and put in a local data base and it will provide via an intranet application. The entire system not requires any supplementary energy supply and interventions in the factory infrastructure. It is experimented in a company from the automotive industries.

1. Introduction

In the enterprise, monitoring of the equipment is needed to increase security in exploitation, decrease maintenance costs and finally affect positively the productivity. There are many solutions for monitoring of the equipment, solutions based on integrated sensors in particular. There are two major problems that arise from integrating monitoring solutions energy consumption and costs of integration. So the mains targets are to optimize energy consumption and to decrease the costs of integration in equipment – it is possible to build a non-invasive monitoring solution which no need to modify the equipment. Paper [1] is a review about the possibilities to supply SMM using non-conventional energy sources. The possibilities are: capturing electric fields (like E-Ocean solution), using radio frequency field, magnetic field, solar, thermal energy and vibrations from static or dynamic sources. In our solution we use only energy captured from electric field.

Paper [2] present a sensor with wireless data transmission applied for two-wire zip-cords. Wireless data transmission integration in self harvesting sensor is also used in our solution. The solution presented in [2] can measure currents under 1 A to maximum 130A, to single phase supply network.



Our solution is used to measure currents for three phase network with values between 1A – 600A. Even if our project profile is to measure 3 phases current, the solution proposed here is very interesting as harvest and acquisition in unbalanced, 1 single phase power network.

Paper [3] presents a self-powered convertor which uses another supply energy source: thermoelectric energy. It implements an adaptive maximum power point tracking (MPPT) technology – same is used in photovoltaic panel controllers – to increase the performance (efficiency is about 63%). In our solution, we use only energy from electric field around cable but the paper present an interesting solution for the improvement of the efficiency in energy harvesting.

In [4] energy harvesting from wind-induced vibrations is addressed. This is another source of energy for sensors which can be used for outdoor systems. We use sensors for indoor or outdoor energy measurement but we have a central unit which can be supplied from non-conventional energy sources (wind or sun power). Another solution in [5] presents a method of cutting tool vibration energy harvesting for wireless data transmission sensor. This solution can be applied for industrial equipment which performs mechanical processes. The solution presented in the paper satisfies the energy needs for sensors and has wireless covering area of 20 m. Our solution has same covering area. Another solution self-harvesting energy solution from mechanical vibrations captured with piezo devices is presented in paper [6]. The solution includes a voltage converter, a buck–boost converter in discontinuous conduction mode and a switching clock generator (used for switching source). The solution has efficiency value of 54%. VLSI ultra-low power technologies are used in [7] where is presented a new integrated piezoelectric energy harvesting system. The controller is designed with ultralow power analogue circuits which have a current consumption of maximum 450 nA. The output power is between 12 μ W to 1.1 mW. The efficiency greater than 70% if achieved for outputs power between 80 μ W to 1.1 mW.

There are more efficient solutions for power consumption monitoring. The solution proposed in [8] allows non-intrusively measurement of power consumption for the equipment with variable demand loads. This paper introduces a method for estimating the real and reactive power consumed for a lab emulated equipment with continuously variable load - Variable Speed Drive. The solution use an algorithm for the power consumption estimation which exploits features of the non-sinusoidal current waveform consumed by many variable power loads. So only a time analysis of the waveform give indication about power consumption – active or reactive. Reactive power consumption give an indication about inductive loads (e.g. motors) activity.

In paper [9], is presented a hybrid system with artificial intelligence and statistical techniques for industrial equipment monitoring and diagnostics. The monitoring method consists of four steps: redundancy creation, state prediction, sensor measurement validation and data fusion, and fault detection. Through these four steps are used the information that can be obtained from sensors which are placed in different parts of the equipment. The system can detect sensor failures (even multiple), in different stages. It can also detect some sensor failures such as drift in calibration and degradation of the sensor.

The current consumption reflects the tasks which are carried out in a time by the equipment. For example, for a turned on motor the power (current) consumption is greater when working under load than is no load. At the same time, the fluctuations of the power consumption may reflect some problems that may arise or already have arisen from the equipment. In our paper, we implemented a system for monitoring industrial equipment which is non-invasive, autonomous energy efficient and flexible. Our solution provides, via intranet, data relating to operating mode of the equipment. These data can be used in more situations:

- To monitoring the operation of the equipment and to determine their working hours and the schedule of the operators who use it;
- To monitoring how the operators use the equipment: when they perform a task, when the equipment is turned on but doesn't perform any task etc.
- To detect certain problems that can occur to equipment, for example: decrease in electrical load (decrease of the consumption) can give an indication of engine problems coupled with work

equipment (loosening of belts for example). In this case, will intervene and appropriate action will be taken by maintenance team.

- To detect the problems and failures that occur at equipment to alert the operators and the maintenance teams.

2. System presentation

The figure 1 presents the block diagram of the system achieved in this paper.

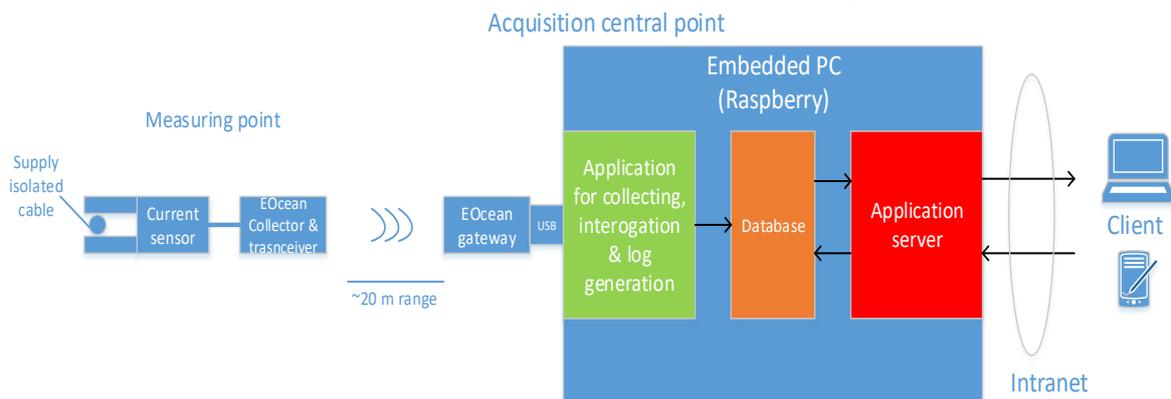


Figure 1. System block diagram.

The system consists of: sensors to measure the current (power) consumption that will be attached to the cable (clamp meter), transmission equipment for remote data transmission (data from sensors) and an acquisition central point connected to the enterprise intranet network.

The sensors are of the type clamp meter, capable to measure the currents from 1A to 200A per single phase 220V or tri-phase 380V supply network. They are integrated with equipment for remote transmission of data.

The transmission equipment allows data transmission on radio frequency 960MHz band free Europe, with a coverage area of about 20m. The equipment is based on chipset from EOcean for acquisition and wireless transmission at low power. Energy needed to supply data transmission equipment and sensors is ensured through self-harvesting from the electric field around the measured conductor.

So, the electric field is used to measure power consumption and to supply the sensors and transmission equipment! Measuring the power consumption is only by placing the clamp-meter around the insulated wire - a method of measurement which is completely non-invasive and autonomous.

The acquisition central point is based on the use of an embedded PC (Raspberry Pi) and a gateway which is also based on a chipset from EOcean. The gateway receives data from sensors via wireless network and then the data are provided to embedded PC. Here, the data are stored in a local database and compared with the data set which represents the equipment profile. Depending on differences noticed, embedded PC will transmit on the intranet network signals on the operating mode of the monitored equipment. The connection between gateway and embedded PC is via an USB port.

The embedded PC will run: an application to collect data, query analysis points and generating logs, an application server and a database server. The application monitoring the gateway and when the data is received it will be stored in the database. The received data will be in a package, in accordance with the specifications of the protocol ESP3 eOcean, figure 2.

u16DataLength	u8OptionLength	u8Type	u8DataBuffer[6]
u8SenderId[4]	u8Status	u8SubTelNum	u8Destination[2]
u8Dbm	u8Security	u8hCRC	u8bCRC

Figure 2. ESP3 eOcean data package.

They will be stored in the database in the format (table Receive) presented in table 1.

Table 1. Receive table structure.

Sender Id	Phase 1 value	Phase 2 value	Phase 3 value	Date & Time
Long	Double	Double	Double	DateTime format

After storing, the data are interrogated and compared with analysis points. Application server (Apache) has a double role. First, provides to the client a web interface to define a device profile (based on his id). Device profile involves storing in the database (Profile table) of the records which define the analysis points of the equipment. The structure of an analysis point is shown in table 2:

Table 2. Profile table structure.

Equipment Id	Phase 1 values min/max	Phase 2 values min/max	Phase 3 values min/max	Type of analysis point
Long	Double/Double	Double/Double	Double/Double	Enum

Type of analysis point can be: CRITICAL, WARNING, INFO.

Each measured value is compared with the corresponding analysis point. If the value enters in the range given by an analysis point, then the system will generate a log which will be written in the table Logs. The structure of a recording of a log is shown in table 3:

Table 3. Log table structure.

Equipment Id	Profile Id	Receive Id	Time & Date
Long	Double/Double	Double/Double	Double/Double

Secondly, the server takes requests from clients and responds with json data packets which contains the logs and measurements from the database. The client may request logs from any equipment for a certain time. The client also can ask raw date, that results from measurements on a certain time. So, the system not only allows real-time monitoring, but it runs some operations that have already been performed on equipment. Thus, when a failure occurs it allows to do an analysis of the operation for to identify the moments that triggered the problem.

3. Experimental results

Two experiments were carried out. First was an experiment in the laboratory by using a variable resistive load generator. Thus, there was analysed the detection capability of the system: the lower limit of detection and resolution (error).

The figure 3 presents a photo taken during the experiment.

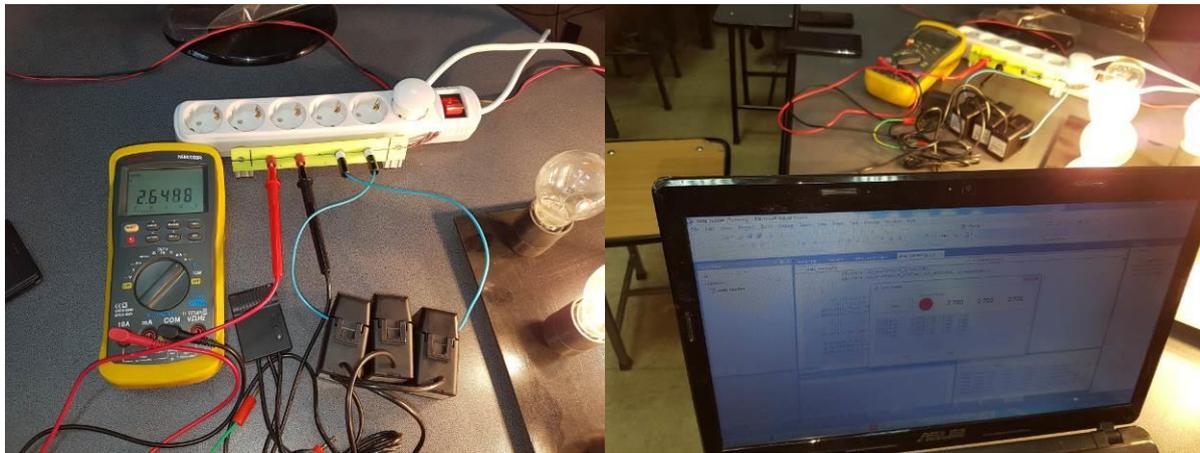


Figure 3. Experiments with monitoring system: left clamp-meters connected to single phase conductor (220V), right data acquisition and display on screen. Current values measured with clamp meters are compared with results from a „classic” amperemeter. Dynamic load is emulated using an array of light bulbs.

The table 4 provides information regarding measuring resolution and minimum detection bound. As we can see, power consumption under 1A causes large errors in measurement due to measuring equipment inability to self-harvesting from electric field.

Table 4. Measuring results compared with an amperemeter.

Measured value (from clamp meter via wireless network) -A	Measured value (from amperemeter) – A	Difference (Error)
2.7	2.657	0.043
2.4	2.41	-0.01
2.1	2.073	0.027
1.9	1.854	0.046
1.6	1.593	0.007
1.4	1.42	-0.02
0	1.17	-1.17

Laboratory tests were performed on a single-phase supply network (220V – one phase: three-meter clamp was placed on the single phase).

The second experiment is the use of the system in the real measuring environment. The gateway capacity is up to 15 measurement/transmission points (sensors and transmitters). We used two measuring points at workstations for printed board circuits mounting. A workstation has a vacuum pump, mounted equipment parts, lamp and an oven.

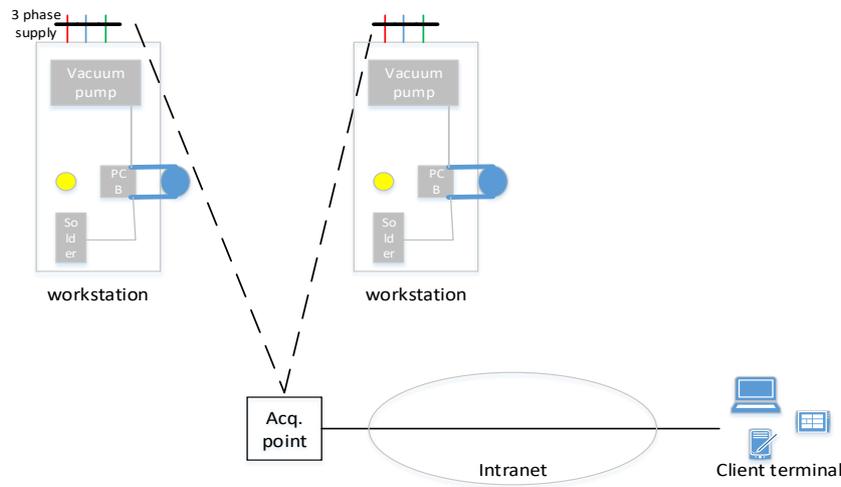


Figure 4. Measurements in real environment.

In the case of more complex equipment we can have different points of measurement on equipment segments.

Figure 5 presents captures with data at the measurement.

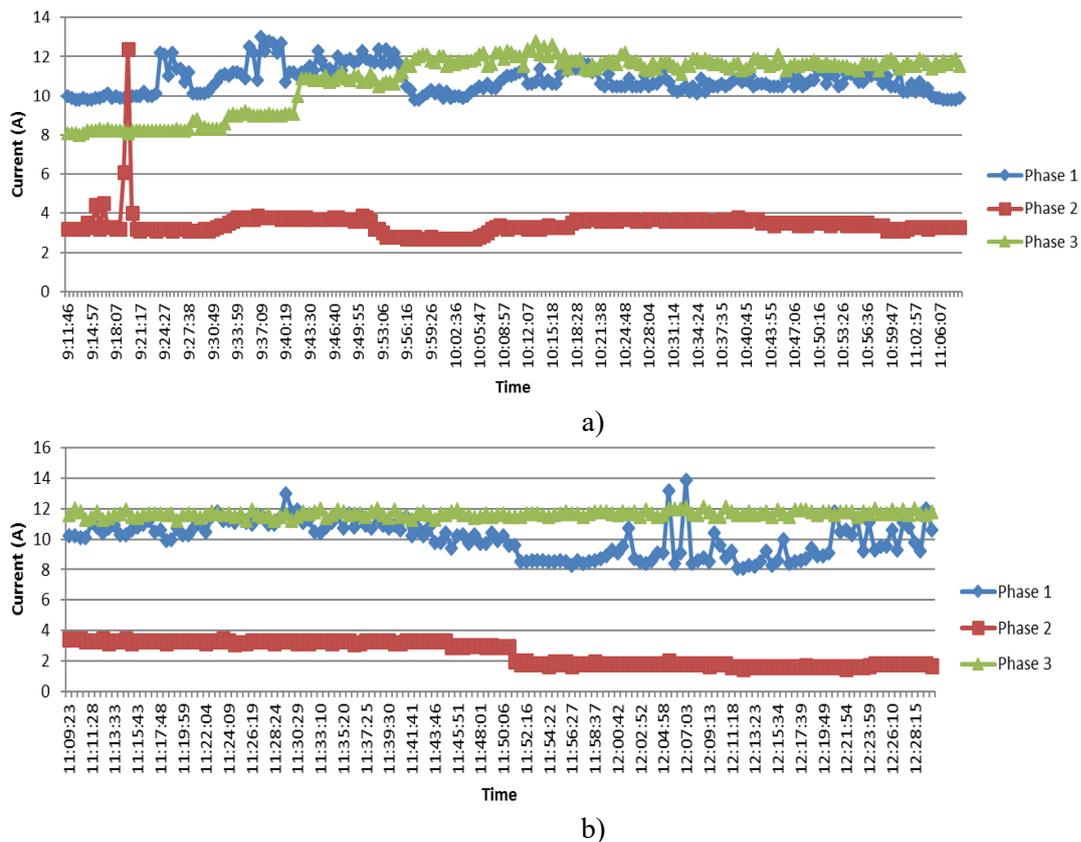


Figure 5. Raw data (measurements) from workstations with different operation modes.

The equipment from workstation is supplied from three-phase power network. You can observe the current fluctuations that occur at various operating modes of the equipment: vacuum pump start - shock at start up or power equipment (lamps, soldering equipment). When turning on the vacuum

pump the current on phase 3 (green) suffered an increase above that of the phase 1 and remains so as long as the pump is started. Along with the analysis of consumption per phase, the system allows correlations between phases providing a more accurate profile on the consumption of the equipment.

4. Conclusions

The monitoring system has many advantages. He can give a precise indication on the work program of the equipment, how to use them and the potential problems that may arise. The system provides a data packet that can be complementary to other information from sensors mounted on the equipment or that can even replace. The solution is a non-invasive - require no further intervention when installing sensors and uses wireless communication to central point, has self-harvesting components - the central point is single powered element: an embedded PC with a consumption regime between 100mW - 1W. The solution is also portable, install it at different points in the factory is very easy.

5. Acknowledgments

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