# Electric Motor Consumption and Condition Monitoring with IoT

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**Abstract.** In the context of Industry 4.0, the industrial landscape is facing significant challenges related to energy consumption and environmental responsibility. The energy demand of electric motors accounts for approximately 70% of the electricity consumption in industries. As the industries strives to reduce its carbon footprint and bolster sustainable practices, the efficient operation and monitoring of industrial assets have become paramount. This paper explores the symbiotic relationship among Industry 4.0, energy efficiency, and environmental responsibility within the industrial context and presents an assets digital condition monitoring solution to estimate energy consumption and CO2 emissions from electric motors, in addition to practical cases. It underscores the importance of adopting smart technologies for asset monitoring and highlights the competitive edge gained through comprehensive insights into carbon emissions, further reinforcing the significance of Environmental, Social and Governance (ESG) considerations in today's corporate landscape.

**Keywords:** Energy consumption, electric motors, CO2 emissions, Condition monitoring, IoT, Industry 4.0, ESG.

## 1 Introduction

The greenhouse effect is a natural phenomenon that keeps the temperature of the Earth's atmosphere within a stable range. The effect occurs through the retention of solar energy, reflected from the surface by six Greenhouse Gases (GHG). The higher the concentration of these gases resulting in an increase in global temperature, known as global warming. The excess emission of GHG is impacting the future of businesses, especially in terms of regulations, reputation, and commercial operations. Companies that fail to adapt to standards will face challenges in obtaining financing and will be negatively evaluated by investors. This highlights the importance of monitoring the electricity consumption of company assets. One of the regulations that the European Union parliament requires is an annual report containing information on the environmental impact caused by the company's operations [1]. This paper highlights the benefits of estimating the consumption of electric motors through Internet of Things (IoT) technology and Artificial Intelligence. The primary method of calculating the estimated consumption and

GHG emissions of electric motors, as per the International Environmental Product Declaration (EPD®) System [6], is quantitatively compared with the estimate calculated through a digital solution that utilizes wireless IoT sensors and a cloud platform. Since the digital solution continuously monitors in a scenario where motors may or may not be operating with variable loads, the estimate calculated through smart sensors proved to be more accurate. Then, the presented solution is an alternative for companies to prepare GHG emission reports with measured data.

# 2 Concepts

## 2.1 Relationship between kWh consumption and GHG emissions

The Greenhouse Gas Protocol (GHG Protocol) provides international standards for measuring and managing GHG emissions [5]. The location-based method consists of a set of average values of emission factors per GHG gas emitted during energy generation by a specific region or country. The present paper focuses on electricity consumption based on the emission factor of Brazil (0.0426 tCO2e/MWh) [3], where the motors used in the case study are located. In this context, to compute the emissions resulting from the operation of an electric motor over a period, simply multiply the energy it consumed by the emission factor of the region.

## 2.2 Calculation of consumption of an electric motor

The life cycle of an electric motor can be divided into 8 phases. Of all these phases, around 98% of GHG emissions on average occur during the motor's use phase, as presented in Section 2.3. This is expected, given that the lifespan of an industrial electric motor can reach 25 years. The present paper focuses on estimates emissions in the use phase of electric motors. Estimating GHG emissions in this phase involves converting the estimated consumption in MWh during the active period of the electric motor into tCO2e. The International EPD® System [6] presents an energy consumption formula $E$ used in this type of estimation, where $P_m$ is the rated power at the shaft in kW, $t_a$ is the active time, $\eta$ is the motor efficiency in %, and $RSL$ is the Reference Service Life.

$$E = \frac{P_m . t_a}{\eta} . RSL \tag{1}$$

## 2.3 GHG emissions for an electric motor

The WEG EcoHub is a software that estimates GHG emissions related to a motor manufactured by the company WEG throughout its lifecycle. It establishes the carbon footprint calculation process, providing reports based on three standards [2, 5, 4] for converting energy consumption into tCO2e emissions. Figure 1 illustrates the values of a carbon footprint report generated for an electric motor. The motor's use stage emits the most GHGs, averaging 98% for industrial motors manufactured by the company.

| Inventory Results: tCO2e/unit of analysis | | |
|---|---|---|
| Total Inventory Emissions | Biogenic Emissions | Non-Biogenic Emissions |
| 331.933 | 0.000 | 331.933 |

| Inventory Results: Percentage of Total Inventory Emissions by Life Cycle Stage | |
|---|---|
| Stage | Value (Percentage of Total CO2e) |
| Material acquisition and preprocessing | 0.148 % |
| Processing | 0.014 % |
| Transport | 0.000 % |
| Use | 99.838 % |
| End of life | 0.000 % |

**Fig. 1.** Table taken from a carbon footprint report generated by the software. For this example, the motor have 45 kW with 100% efficiency.

The system calculates the estimate of energy consumed during the motor's use stage based on Equation 1. In this regard, standard average values of 25 years are used as the Reference Service Life ($RSL$) and 6500 hours per year as the active time ($t_a$). The values of rated power ($P_m$) and efficiency ($\eta$) are those recorded on the motor nameplate. These are nominal values of the motor, meaning for operation at 100% load.

## 3 Development and Methods

### 3.1 Digital solution for estimating the energy consumption of electric motors using Artificial Intelligence

This paper presents a case study where 2 motors are installed in a factory. Each of these is equipped with IoT sensors that collect data on vibration, magnetic field, and temperature and upload it to a cloud platform. The system estimates rotation, frequency, load, and consumption and delivers more precise inference of data regarding the motors use stage. How this information is computed is explained in Section 3.2. The data used in the case study were collected from July 2023 to February 2024.

### 3.2 Wireless IoT Sensors and Cloud Platform

In recent years, significant advances have been made in the development of IoT sensors and wireless communication technologies, offering new opportunities for remote and real-time monitoring of electric motors, as well as other assets in the industry. All data is transmitted to a cloud platform called Motion Fleet Management (MFM) using Bluetooth 5.1 technology, either through a smartphone application or via Bluetooth gateways, as illustrated in Figure 2. The MFM platform offers intelligent and proactive management of an electric motor fleet. By using IoT wireless sensors in conjunction with Bluetooth communication, it is possible to implement strategies for preventive maintenance, predictive maintenance, and performance optimization.


**Fig. 2.** Schematic of the digital solution.

### 3.3 Method for estimating load and consumption of electric motors

The process of estimating the load begins with the measurement of the motor's magnetic field by the IoT wireless sensor. The magnetic field signal is processed through intelligent algorithms in the MFM, which then determines the motor's rotation. With the rotation and the electromechanical characteristics of the motor (nameplate data), the load is estimated. With this information, the rated power at the shaft is calculated, and with the motor's operating time, the consumption is obtained. To evaluate the reliability of the load determination method with the digital solution proposed in this paper, 36 electric motors ranging from 5.5 kW to 37 kW were tested in the laboratory using dynamometers to impose load on the motors. These motors had frequencies of 50Hz and 60Hz and were 2 and 4 poles with IEC 132 to 200 frames. The average estimation error of the load, comparing the load imposed on the motor by the dynamometer and the digital solution, was 6.2%, as shown in Figure 3. Note that the estimation error is smaller for higher loads.

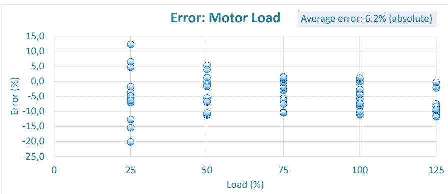


**Fig. 3.** Error in load estimation with the digital solution.

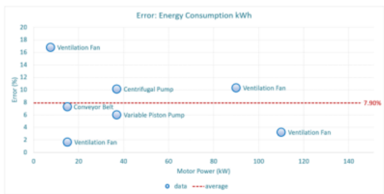


**Fig. 4.** Error in estimating consumption with the digital solution of seven electric motors.

To validate the consumption estimation process, seven motors were analyzed for different applications (pumps, fans, and conveyor belts) installed in WEG's factory. The estimated consumption value by the digital solution presented here was compared with the consumption measured by a power analyzer. The motors were from 10 kW to 110 kW. The comparison was during a one-week for each motor. The average error for consumption estimation was 7.9%, as shown in Figure 4. Based on the measured data and assuming a conservative approach given the large universe of motors, the error of the digital solution presented here in determining the energy consumption of electric motors was established as approximately ±10%.

# 4 Results

## 4.1 Energy consumption and tCO2e emissions of electric motors

In this section, the results of the energy consumption of two electric motors over a period of 6 months is presented. A comparison is made between the estimated value, calculated by the digital solution presented in this paper, and the calculated value according to Equation (1) of the International EPD® System. The analyzed motors are:


**Fig. 5.** Motor 3,7kW/ 4 poles/ 380V/ 60Hz/ 1730rpm/ Frame IEC100L/ η=83,5%/ Application: pump.

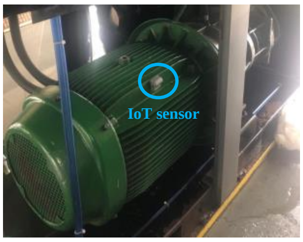


**Fig. 6.** Motor 75kW/ 2 poles/ 380V/ 60Hz/ 3575rpm/ Frame IEC250 / η=95%/ Application: compressor.

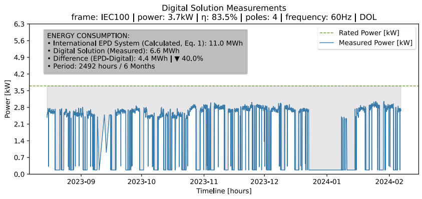


**Fig. 7.** Energy consumption by digital solution – 3.7 kW motor.

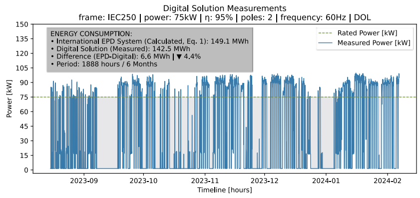


**Fig. 8**. Energy consumption by digital solution – 75 kW motor.

Figures 7 and 8 present the results of the absorbed power of the 3.7 kW and 75 kW motors, connected to the grid. These values were measured by the digital solution (IoT sensor + gateway + MFM platform). With this information and the operating time during this period, it was possible to estimate the energy consumption of the motors. The main result of this is the comparison of the value estimated by the digital solution with the value calculated by the International EPD® System. It is observed that the consumption value calculated by the EPD®, for these two cases, is above the value measured by the digital solution. This occurs because the rated power of the motors used in Equation 1 is always 100%. However, in practice, the motor does not always operate at 100% load. For the 3.7 kW motor (Figure 7), this difference is evident. For this motor, during the 6 months, it is observed that the consumption was approximately 60% of the nominal value. Consequently, with greater precision in the consumption estimate, there will be greater precision in determining tCO2e emissions per motor during the life cycle.


**Fig. 9.** Digital Solution Dashboard - tCO2e emissions for 3.7kW and 75kW motors.

The Figure 9 is an example of the dashboard that the user will have access to when using the proposed digital solution. The information will be available on the MFM platform as long as the electric motor to be evaluated is equipped with a wireless IoT sensor and has the necessary settings and access, as shown in the diagram in Figure 2.

## 5 Conclusion

This work presents a proposal for a digital solution consisting of a wireless IoT sensor, gateway or smartphone and cloud platform (MFM) that estimates the energy consumed by electric motors. The practical cases presented for 3.7kW and 75kW motors showed the advantage of using this solution compared to the calculation currently established by the International EPD® System. The difference is that the digital solution determines the actual load on the motor and thus allows for a more accurate estimate of the electrical energy consumed, while the EPD® calculates consumption considering the motor is always operating at 100% load. Understanding that, through ESG principles, international policies and society are increasingly demanding a reduction in CO2 emissions, the solution proposed here will help companies and industries to more accurately determine the tCO2e emitted by electric motors.

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