PROPOSAL FOR METHODOLOGY TO ANALYSE OPERABILITY OF WINE PRODUCTION PLANT IN TERMS OF POWER DEMAND

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Abstract. In the industrial plant context, especially in the case of a large increase in production, the risk of layering new acquisitions on top of an existing layout without questioning previous choices can lead to increasing inefficiencies. Under these conditions, the analysis of power demand in a reference period is a useful activity to be carried out. Therefore, a very fast and easy approach, based on the analysis of the energetic behaviour of an existing plant, in the present case a wine production facility, is proposed here with the aim to support management in addressing efficiency choices. It foresees, first of all, the acquisition of electricity consumption printouts, relevant to the last few years and detailed up to the day, from the national energy provider. Then, thanks to some analysis on weekly, monthly, seasonal and/or yearly trends, it is possible to evaluate: the basic power absorption levels (e.g. due to the plant auxiliary services, production machinery, product storage cells), the surplus power absorption levels due to seasonal trends (i.e. due to different environmental weather conditions) and the peaks due to the core production activities (concentrated mainly during the autumn, i.e. after the grape harvest). This approach allows connoting an industrial plant basically with two metrics, i.e. numerical parameters, both mathematically expressible as ratios between homogeneous quantities referred, respectively, to power demand levels and to periods of the year with different power demands. In the examined case, the analysis revealed a strongly-connoted yearly trend that evidences the existence of two, very different periods: an ordinary and an extraordinary period, corresponding to the grape harvesting term, having a "duration ratio" of 0.18 (18% of the year) and a "power request level ratio" of 4 (+300% of increment on the average request). The period with the higher request is, therefore, very short but intense in its power demand. This first analysis, together with the "weekly normalized average profile of power request" (second tool belonging to this methodology), allow evidencing: (1) the contribution of the activities, related to the wine making process, to the net increase of power demand, and (2) the possibility to flatten the weekly trend, now having a decrease of about 0.45-0.50 normalised power units between the working week and the weekend, by attributing some consumption to Saturdays and Sundays, e.g. by providing for a different staff rotation.

Keywords: energy management, power demand surpluses, energy-efficiency strategy, possible renewal of the plant machinery, 2-factor analysis of a plant operation.

Introduction

In recent years, the wine sector has witnessed a strong growth in terms of visibility, productive volume and also energy consumption. At the same time, reducing primary energy consumption and related greenhouse gas (GHG) emissions are one of the pillars of the 2050 European strategy, which aims at reducing GHG emissions and increasing the share of energy obtained from renewable sources [1]. The wine sector, other than being a strategic sector for the European Union (EU), is still linked strongly to the use of fossil fuels. According to the "TESLA" EU-funded project [2], the consumption profile of wineries at the EU level is 1,750 million kWh per year. In Italy and France, energy consumption is roughly similar and around 500 million kWh, in Spain it is around 400 million kWh and in Portugal 75 million kWh [3]. According to [3], the primary source of energy used is still fossil-generated electricity (92%). Fossil resources (e.g. diesel oil and other fuels) are consumed for thermal processes (e.g. heating water for bottling) but account for about 10% of the total energy consumption. Rather, in most wineries, the electricity accounts for 70-80% of total energy consumption [4], e.g. to operate equipment, such as pumps or presses, for the room illumination, or for refrigerating the product in several processes. In Catrini et al. [5], a brief characterization of energy use in the winemaking process is provided. It is noteworthy that 45% of energy is surely consumed to control fermentation processes [6], mainly by cooling systems in fermentation tanks.

Numerous studies have focused also on the energy consumption of wineries per unit of product [2; 5; 7]. In Italy, mean electricity consumption is around 0.20-0.35 $kWh \cdot L^{-1}$ [8]. Another study by Smyth and Nesbitt reviewed the energy used in the English context, assessing an average of above 0.50 $kWh \cdot L^{-1}$ [7].

When tackling an improvement process, it is essential first of all to understand "where" and "when" energy consumption is requested within a company and, to achieve this purpose, an energy breakdown analysis is used [9]. In general, energy demand is closely related to seasonality [10]. Botner [11] analyses how a significant share (40-60%) of the electrical energy consumption relates to the product refrigeration phases and to the heating and cooling phases of the work environments. Technologies and energy consumption are also strongly related to the type of wine produced. Indeed, white winemaking requires more different technologies and methodological approaches than red winemaking. Moreover, in the case of sparkling wine production, all the activities and technologies related to refermentation should also be considered. Despite these differences, there are multiple points of commonality among the different production approaches. For example, the pressing stage, the alcoholic fermentation and the stabilization stage are steps that are common to all supply chains and impact for more than 50% of the energy consumption on the entire processing chain [2].

All these studies aim at obtaining a breakdown of energy consumptions, but they evidence the lack for a quick methodology to be used *in a preliminary phase*, prior the application of the above-illustrated analytical decomposition of consumptions and costs. Therefore, the aim of this study is to illustrate a fast and easy methodology to evaluate the consumption profiles of a wine cellar and identify, in the first instance, some points of interventions and possible actions that can be taken to set up a roadmap for increasing energy efficiency. This method will be illustrated on a specific case-study, i.e. an Italian winery producing still white wines and Prosecco, and the consumption profiles over a representative period of time have been analysed and discussed.

Materials and methods

The methodology proposed in this article is articulated in the following steps:

- acquisition, from the energy service provider, of electric consumption data, in terms of active and reactive power absorbed from the national electricity grid every quarter of an hour, related to a one-year survey period (i.e. the typical reference period for wine cellars, due to their regular cyclicity of production processes);
- first processing of the data to have daily-monthly-yearly power demands, and formulation of some considerations regarding consumption trends on a monthly-seasonal-annual scale;
- identification of the absolute maximum peak of electric power demand on an annual scale, and of the average and minimum level;
- in the case of power requests with a seasonal trend, identification of the upward and downward ramps of the request graph, and partitioning of the annual graph into periods of different power requests (*ordinary periods*, therefore with a constant and minimum or "basal" demand; *extraordinary periods*, therefore with a demand above the minimum); possible year-after-year weather variations (above of all in terms of ambient temperature), as well as possible variations in the mass of delivered grapes have a direct (proportional) influence on the power demand variation, without significantly affecting the overall morphology of the power request curve, still presenting the two above-illustrated periods of different power requests;
- second processing of data to obtain a daily cumulative consumption; then, for each of the previously-identified periods, calculation of the average energy consumption per day of the week (average daily consumption levels of a typical week);
- identification, within each typical week, of the maximum and minimum energy demands and the duration of the periods with a demand above the baseline.

After applying the proposed methodology (which could be referred to as "*2-factor analysis of a plant operation*"), it is possible to identify two metrics acting as summarising numerical parameters of the operation of a generic company, referred both to the annual and to a weekly time scale, i.e.:

- the "*power request level ratio*", i.e. the ratio between the absolute maximum of power demand in the extraordinary period and the average level of power demand during the ordinary period;
- the "*duration ratio*", i.e. the ratio between the total duration of the period(s) with consumption above the basal level (extraordinary periods) and the duration of the period(s) with ordinary consumption.

Thanks to these two parameters, it is possible to formulate some considerations regarding:

1. the possible over-dimensioning of the energy supply lines carried out during the installation phase;

2. the maximum power available from the national grid operator and reported on the contract (influencing the pricing of the energy supply).

In addition, it is possible to easily highlight any critical point in the power demand level to proceed, at a later stage, to identify possible measurement points in the plant layout aimed at performing a further breakdown of the plant's energy needs.

The presented methodology has been applied to the power absorption data of a plant that is part of an industrial winery located in the North-East of Italy. This facility has an annual production capacity of 24 million bottles (mainly of white sparkling wine "*Prosecco*") thanks to a grape-conferring area of about 2000 ha.

Results and discussion

The following graph (Figure 1) illustrates the annual trend of active power demand at the electrical power supply cabin of the considered winery, normalised on the average annual power level. The reactive power, in this case, was negligible and always under control, and, for this reason, was not analysed in this study.

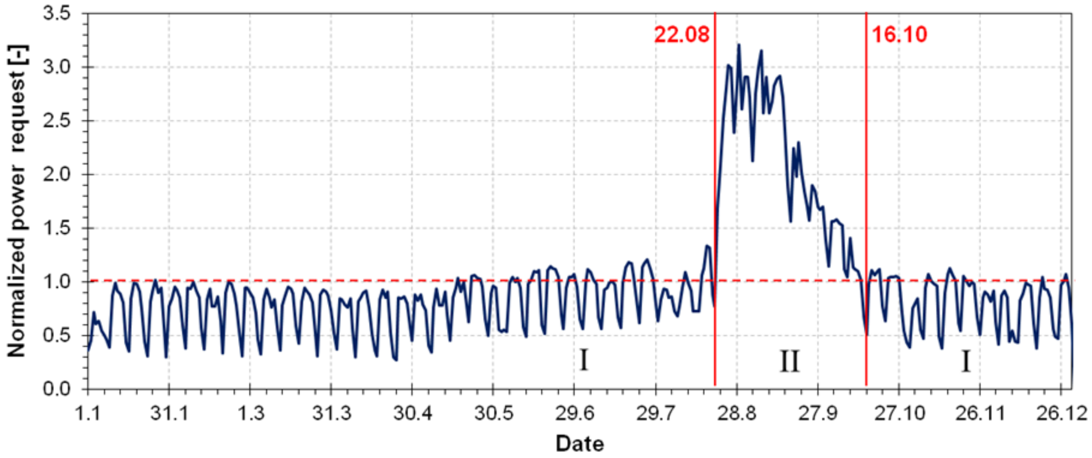

Fig. 1. **Annual trend of active power demand for the selected industrial winery** (I, II: different periods of the year, as individuated in the text according to power request levels; see text)

As it can be seen from the graph of Figure 1, since we are dealing, in the present case, with activities related to wine production, there is a unique increment of the plant's activity over the year span, in coincidence with the grape harvest period (i.e. the months of September and October). The observable trend, therefore, has an annual periodicity, as expected, considering the processed commodities. If "1.0" is the overall average level of power demand, calculated on an annual basis, the ordinary power demand span between 0.3 and 1.3, i.e. it has an average value at about 0.8 (with very slight differences over the year, due to the different environmental temperatures), whilst the maximum power demand reaches 3.2, thus a value that is 4 times greater than the average value of the rest of the year (increase: + 300%). The values of ordinary power demand never fall close to zero due to the need for the vinery to keep active some essential services for the plant (e.g. hot/cold conditioning units, water recirculation pumps). Rather, the recorded high increment of power absorption could be problematic in terms of plant design and management. Indeed, the presence of such a peak acts like a tight and mandatory constraint for the dimensioning of the electrical switchboards and for the indication of the maximum level of power availability from the electricity supplier. This fact has two types of repercussions on the winery's production costs: investments in electrical installations (and related safety systems) will be surely higher, as well as the tariffs charged.

Furthermore, by observing the graph of power absorptions and the graph of the moving average of the first derivative of these power absorptions (Figure 2), it is also possible to identify the start date of the period of increased power demand, i.e. the 22nd of August. In correspondence to that day, indeed, there is a very sharp increase of the power demand curve (Figure 1), indicated by a clearly positive value of the first derivative curve (Figure 2). Similarly, by observing the decreasing trend of the curve of power absorptions (Figure 1) from the peak and the negative values of the derivative profile (Figure 2), it is possible to identify the 16th of October as the date of return of power absorptions to the basal level.

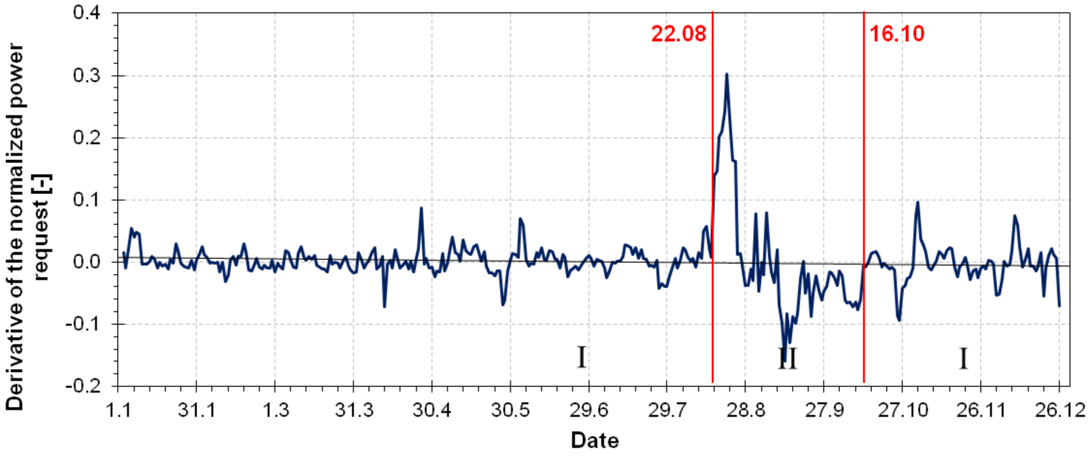

Fig. 2. **Moving average (over 7 days) of the first derivative of the annual trend of active power demand for the selected industrial winery** (I, II: different periods of the year, as individuated in the text according to power requests levels; see text)

The observed asymmetrical trend of the power absorption curve (Figure 1), having two different values for the slope, is typical of industrial wineries: there is, indeed, an initial very sharp increase of activities (with an increase of 0.45 normalised power absorption units per day, corresponding to +56 percentage points per day with respect to the average value of 0.8 for the normalised power absorption outside of the grape harvest period), in correspondence with the arrival of the first lorries of grapes, followed by a gradual decrease of power demands (decrease of 0.05 normalised power absorption units per day, corresponding to -6 percentage points per day with respect to the average value of 0.8 for the normalised power absorption outside of the grape harvest period), as the processed must is sent to the refining sections to be shipped as wine in bottles or barrels. The year has therefore been divided into two macro-periods:

- *I period - ordinary power requests*, from 01.01 to 14.08 and from 16.10 to 31.12 (for a total of 44 weeks, i.e. 84.6% of the year);
- *II period - extraordinary power requests*, extended over the rest of the year (for a total of 8 weeks, i.e. 15.4% of the year).

The ratio between these two periods (extraordinary/ordinary) is equal to 8/44 = 0.18, meaning that the period of extra power request is quite short over a year. With such a situation, it is justifiable to resort even to removable auxiliary means to meet the increased demands. In fact, according to the winery staff, containerised refrigeration units rented for a few months a year (2, for the precision), corresponding to the previously identified-period of increment of the power demand, are used to satisfy all the demands for low-temperature heat-transfer fluids (e.g. for the removal of the heat originated from the fermentation activities of the musts).

Analysing the weekly normalized average profiles of power demand (Figure 3), generated by calculating the average power requests day-of-the-week by day-of-the-week for the two above-individuated periods, and comparing the curve related to the grape harvest period with the curve for rest of the year, it is possible to notice that the trends are morphologically similar, although the gap between working days and public holidays is smaller during the grape harvest period (+30% in the harvest period and almost double during the rest of the year).

During the grape harvesting period, weekly power demand averages twice as much as during the rest of the year and it is heavily concentrated from Monday to Friday (i.e. in the working week). The peak is reached on Wednesdays (normalised value: 2.24) and then there is a slow decrease that stabilizes over the weekend at values well below 2 units (normalised value: 1.79 on Sundays).

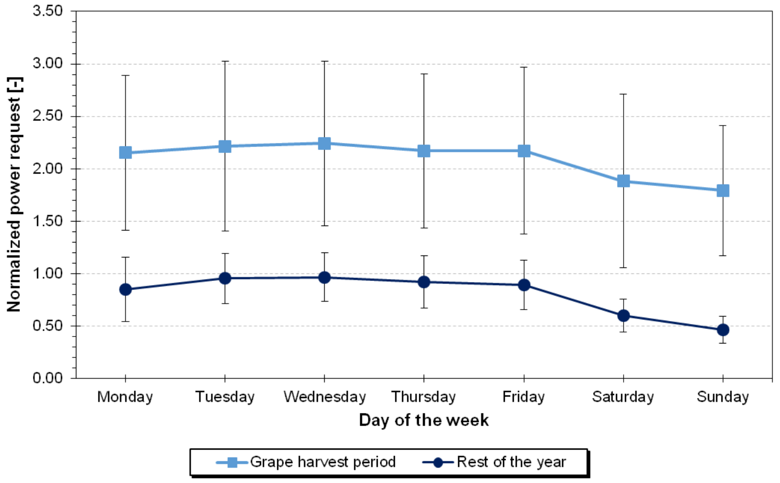

Fig. 3. **Weekly normalized average profile of power request; error bars correspond to a standard deviation**

The similarity, to be intended also as equality of the difference of normalized power levels between the minimum and the maximum power requests (0.45 for the grape harvest period; 0.50 for the rest of the year), means that the principal difference between the two reference periods pertains almost exclusively to the base level of power requests, well evidenced by the values of Sundays (0.47 vs. 1.79, i.e. + 1.32 normalized power units). This is basically due to the operation of the conditioning systems of many fermenter tanks.

Finally, the error bars reported on the same graph (Figure 3) are indicative of the recorded day-after-day fluctuations of power absorptions. By looking at them, it is possible to observe that fluctuations in the grape harvest period are more than 3 times wider than the fluctuations related the rest of the year in correspondence to the same days of the week. This is indicative of existing problems, e.g. due to a lack in planning: (1) the arrival of the wine-growers or (2) the activation of the machinery, operating in a sort of state of emergency characterized by frequent coincidence periods.

Conclusions

- The proposed two-factor analysis of the operation of an industrial winery revealed that power demands are concentrated in a very short period of the year (covering only 18% of the year, corresponding to the grape harvest) and reach a very high level (4 times the average level recorded during the rest of the year). Based on this, it can be stated that some interventions should be evaluated to, at least, contain the increase in power demands.
- An aid to guide the intervention of analysts at this purpose could rise, for example, from the analysis of the weekly normalized average profile of power request, also part of the proposed methodology. By looking at this graph, it is possible to quantify the net increase of power demand due to all the activities related to the wine making process (+ 1.32 normalized power units, substantially constant on all days of the week), difficultly avoidable unless the process is modified. A possible point of intervention, rather, could be the flattening of the weekly trend, now having a decrease of about 0.45-0.50 normalised power units between the working week and the weekend, by attributing some consumption to Saturdays and Sundays, e.g. by providing for a different staff rotation. Furthermore, the wider fluctuations of the day-after-day power absorptions (more than 3 times than in the ordinary period) have evidenced some problems in planning the activities related to the grape harvest (i.e. the arrival of the wine-growers, the activation of the machinery). This is another point of intervention and it surely requires a monitoring period directly on the facility to distinguish between possible internal organisational problems and logistic problems to plan proper corrective actions.

In conclusion, the proposed approach has proven to be successful in targeting the wineries' initial energy efficiency strategy and gaining greater awareness of their performance. The proposed methodology can be seen as the first step in a broader approach aimed at punctually characterizing the behaviour of the production site in order to identify the critical areas, their underlying causes, and the related opportunities of improvement from a plant, technological and process perspective.

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