ASSESSMENT OF THE POWER CURVE FLATTENING METHOD: AN APPROACH TO SMART GRIDS

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ABSTRACT

This paper presents an assessment of several methods to analyse power curve flattening in power systems. Several functions are commonly used to evaluate the flattening of the power demand curve. However, due to the high deployment of Smart Grids, an evaluation of the suitability of the power curve flattening parameter is needed in current power systems. Results are thus of a valuable interest for both Distribution System Operators and Transmission System Operators, who will be able to assess their Smart Grid Projects with a higher degree of accuracy. The developed work is based on the Smartcity Málaga Project led by ENDESA and ENEL.

I. INTRODUCTION

Power demand curves describe power consumptions according to the time of the day. As an example, Figure 1 shows the power curve for December, 15th 2013 of Spain obtained from the Spanish Transmission System Operator, Red Eléctrica de España (REE). In this figure, current demand (depicted by yellow color) shows the instantaneous value of electricity consumption at the specified time of the day. A peak value over 32 GWh and a valley minimum consumption with more than 10 GWh of difference with the maximum can be seen. Demand forecast (green color) is calculated by REE based on historical electricity consumption data from similar periods, adjusted by working and seasonal patterns, as well as the economic activity. Finally, red color shows the scheduled production of the generating units which have been allocated the responsibility for supplying the electricity required to meet the forecasted demand.

Although the consumption profile shown in Figure 1 represents only one day, it reflects the common shape of daily power demand profiles in winter for Spain. Similar profile shapes are found in developed countries [1], [2]. This common profile is usually composed of two peaks: the first one usually occurs between 10:00 and 14:00, and the second one is usually placed in the late evening (between 20:00 and 22:00). Also, the daily power demand profile usually contains a valley region (also known as off-peak region), whose lowest value is

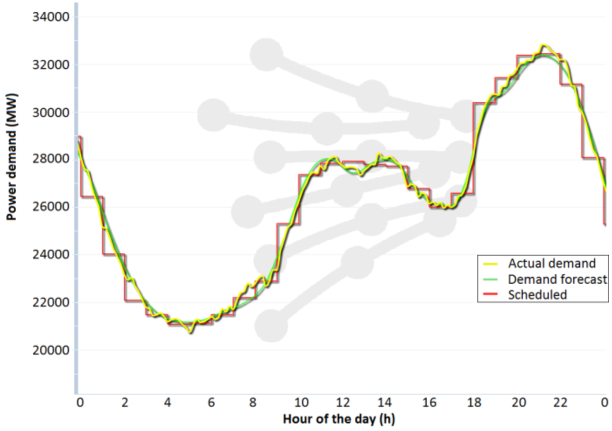

Figure 1. Electricity demand on the Spanish peninsula during December 2013, the 15th.

commonly located early in the morning, between 03:00 and 05:00.

The design of power system networks implies that these have to be dimensioned for a safe load supply during peak load hours [3], which occur a few hours a day as can be deduced from Figure 1. Nevertheless, this is an uneconomical situation since networks are thus oversized for the rest of the year.

Under this framework, the implementation of appropriate incentives and efficient energy consumption scheduling algorithms is a primary goal for the Smart Grids, SGs, [4]. Basically, the SG concept integrates information and communication technology systems into the power system in order to meet several objectives, [1]. On the one hand, from the customers point of view, SGs suppose an increase of economic savings, comfort, social responsibility and awareness. From the power system utilities point of view, the increase of system efficiency and cost effectiveness, as well as the improvement of reliability and power quality appear as one of the most important issues involved in SGs. One of the means used to achieve the previous goals is the flattening of the power demand curve. This implies the use of different cost-effective initiatives to reduce or move peak consumptions to valley hours, such us batteries [3], demand response management [5], [6], new tariff structures [2]…

Taking previous ideas into account, the present paper evaluates several methods commonly used to assess the flattening of the power demand curve. Several demand curves based on real measurements are used to study the influence of different weighting parameters over the flattening equation proposed. The developed work is based on the Smartcity Málaga Project led by ENDESA and ENEL. The paper is structured as follows: After this introduction, different methods to assess the flattening of the demand curve are discussed in section II. Section III presents the methodology and proposal developed in this work and section IV provides the results dealing with the use of this method. Finally, section V collects the conclusions.

II. REVIEW OF POWER DEMAND CURVE FLATTENING METHODS

One of the means commonly used to assess the flattening of the power demand curve is by the calculation of the system peak factor [2], also known as load factor [7]. This factor, called as M_1 in Eq. (1), gives the rate between the maximum peak demand and the average demand during a specified period of time. In the present work the period of time considered is 24-h (daily profile).

$$M_1 = \frac{\max(P_h)}{average\,(P_{h1:h24})} \qquad (1)$$

Where, P_h represents the power P consumed at hour h.
High load factors indicate a very low efficiency for the local distribution system capability to carry electricity, whereas low numbers indicate a high efficiency. A typical load factor value for homes is 2 [8].
In addition, some other factors have to be considered in order to carry out a complete assessment of the power demand curve. In this way, two additional factors are proposed in the present work. On the one hand, the rate between maximum and minimum power consumption is identified as a factor directly associated with the flattening of the power curve, Eq. (2). In fact, an ideal flat power demand curve would provide a value $M_2 = 1$. On the other hand, it becomes also important to take into account the utilization factor. This factor describes the rate between the capacity of the line currently used and the capacity of the line in the case of maximum consumption during 24 hours, Eq. (3). Actually, (3) provides knowledge about the oversized network degree due to the maximum peak.

$$M_2 = \frac{\max(P_h)}{\min(P_h)} \qquad (2)$$

$$M_3 = \frac{\sum_{i=1}^{24} P_h}{24 \cdot \max(P_h)} \qquad (3)$$

III. DESCRIPTION OF THE DESIGNED METHODOLOGY

Taking into account the equations described in Section II, and based on a daily time period, Eq. (4) is proposed as the only function to assess the flattening of the power demand curve, being *FF* the flattening factor.

$$FF = W_1 \cdot \left[\frac{\max(P_h)}{\min(P_h)}\right] + W_2 \cdot \left[\frac{\max(P_h)}{average(P_h)}\right] + W_3 \cdot \left[\frac{\sum_{h=1}^{24} P_h}{24 \cdot \max(P_h)}\right] \qquad (4)$$

Three weights (W_1, W_2, W_3) associated with the three addends involved in (4), which were presented in Section II, are included in the proposal. Once defined the equation proposed, five power demand curves have been selected to assess the suitability of the three weights included in the equation:

- Curve 1: the first demand curve taken into account is the ideal situation, which is defined as a completely flat demand curve (also called as constant power demand curve). This ideal power curve will be able to provide comparable results with respect to the other demand curves.
- Curve 2: real power demand curve. Concretely, the real profile considered in this work is shown in Figure 1.
- Curve 3: this curve is a modification of curve 2. Specifically, the second peak of curve 2 is removed. This is performed through doing constant the power consumed at 18:00 until 23:00.
- Curve 4: this curve is a modification of curve 2. Specifically, the valley region of curve 2 is removed. This is performed through doing constant the power consumed from 02:00 to 09:00.
- Curve 5: this curve is a modification of curve 3. The valley region of curve 3 is removed. Therefore, after curve 1, curve 5 is the flattest power demand curve as this curve behaves as if peak hour consumptions are moved to off-peak hours.

Figure 2 presents the previous considered list of power demand curves. The ideal curve (curve 1) is drawn with black colour and each power value is marked with circles. It is clearly seen that this ideal curve has a constant value. Then, curve 2 has a higher width because this curve represents the real daily power demand curve of the Spanish Power System shown in Figure 1. Curve 3 follows the profile of curve 2 until 18:00 because from this hour the consumption is assumed constant. Curve 4 has also the same profile as curve 2, but with the exception of the constant consumption between 02:00 and 09:00. Finally, curve 5 results as the combination between curves 3 and 4, which is clearly shown in Figure 2.

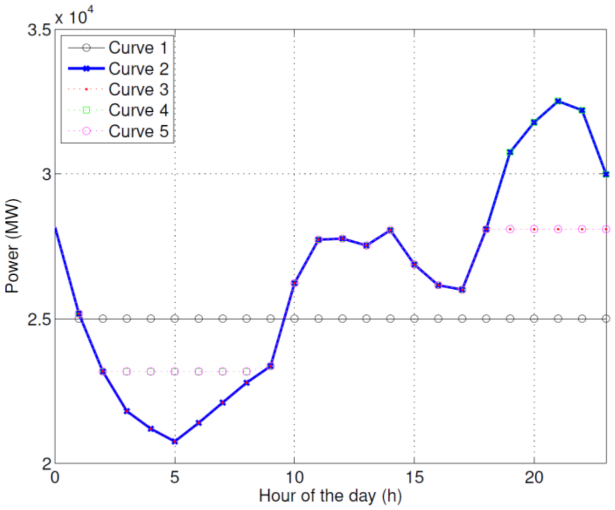

Figure 2. List of power demand curves used in this work.

IV. RESULTS

Several analyses have been carried out to assess the suitability of the three weighting parameters included in the flattening demand curve equation, (4).

IV.I Comparison of identical profile shapes

The first study is aimed to analyse the effect of the weights over three power demand curves with identical profiles. Concretely, curve 2 (see Figure 2) has been selected as the reference curve, whereas the other two profiles are obtained by just moving up and down, respectively, each value of power consumed at each hour. Considering these identical profiles, seven groups of weights (also referred as weight groups, WG, or set of weights) have been selected, as described in Table 1. As can be seen, the sum of the weights is equal to 1 in all the configurations, but the value of the weight is changed between configurations. For example, the first set of weights provides identical level of importance to the three addends shown in (4).

Table 1. Weight groups (WP) used for calculation.

	W_1	W_2	W_3
WG_1	0,33	0,33	0,33
WG_2	0,50	0,25	0,25
WG_3	0,25	0,50	0,25
WG_4	0,25	0,25	0,50
WG_5	0,90	0,05	0,05
WG_6	0,05	0,90	0,05
WG_7	0,05	0,05	0,90

The previous list of weights has been used to obtain the flattening factor, FF, defined in (4) for the three demand curves with identical shape considered. Results are presented in Table 2. As it can be seen, for any specified set of weights (WG) the FFs calculated are constant. Actually, this is an interesting result, because it implies that the assessment of the demand curve flattening depends on the shape of the profile, which is a necessary requirement to define a suitable demand curve flattening method.

Table 2. Flattening factors obtained with three identical power demand profiles.

	Curve 2	Moved up curve 2	Moved down curve 2
WG_1	1,2036	1,2036	1,2036
WG_2	1,2942	1,2942	1,2942
WG_3	1,2115	1,2115	1,2115
WG_4	1,1051	1,1051	1,1051
WG_5	1,5116	1,5116	1,5116
WG_6	1,2306	1,2306	1,2306
WG_7	0,8686	0,8686	0,8686

IV.II Assessment of the influence of the weight parameters value on the FF

This section evaluates the influence of a wide range of weights on the flattening factor calculation. The five power demand curves depicted in Figure 2 will be used. The criteria for the selection of the best set of weights will be that set of weights that order the demand curves by their flattening. This means that curve 1 must be the first (this is ideal, constant power curve), the second best should be curve 5, curve 2 should be the worst, and both 3 and 4 curves should be in the middle. The order is given by the proximity to value 1, which represents the constant flattening factor value given by the ideal flat power demand curve.

Under the previous framework, and taking into account the group of weights (WG) previously defined in Table 1, the calculated FFs are presented in Table 3. In order to obtain a graphic view of the results, Figure 3 summarizes the information contained in Table 3. Obviously, the FF of curve 1 is constant equal to 1 because this is the ideal flat power demand curve. As can be clearly seen, the seventh set of weights cannot be accepted because it provides almost the same flattening factor value for curves 3 and 5, whereas curve 3 is less flat than curve 5.

Table 3. Flattening factors obtained in the five curves with seven set of weights collected in Table 1.

	Curve 1	Curve 2	Curve 3	Curve 4	Curve 5
WG_1	1,0000	1,2036	1,1218	1,1473	1,0739
WG_2	1,0000	1,2942	1,1805	1,2112	1,1092
WG_3	1,0000	1,2115	1,1162	1,1650	1,0763

WG_4	1,0000	1,1051	1,0688	1,0657	1,0361
WG_5	1,0000	1,5116	1,3213	1,3645	1,1940
WG_6	1,0000	1,2306	1,1027	1,2074	1,0821
WG_7	1,0000	0,8686	0,9415	0,8699	0,9456

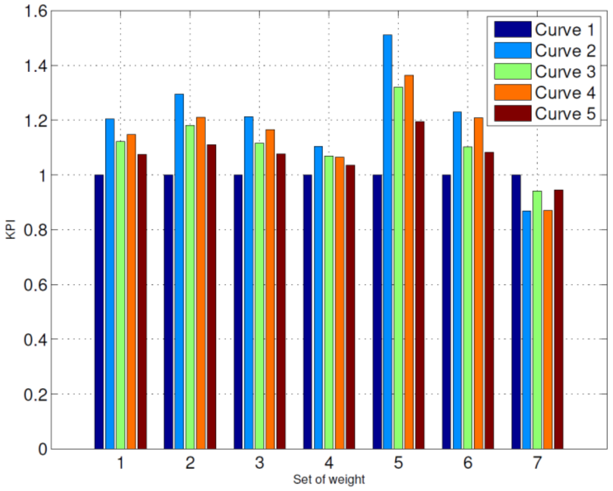

Figure 3. Flattening factors obtained in the five curves with seven set of weights collected in Table 1.

With the aim of studying in detail the influence of the value of the weights over the flattening factor, an extensive study is carried out in the following. For this purpose, a total amount of 66 sets of weights are selected. These sets of weights represent all the weight values combination possibilities between 0 and 1 using 0,1 steps. Additionally, the 1/3 set of weights has been added in the last row of weights to be used. Therefore, the total number of weight groups considered is equal to 67. As an example, Table 4 summarizes some of the first fifteen weight groups used in this comprehensive study.

Table 4. Some of the weight groups (WP) used for calculation.

	W1	W2	W3
WG_1	0,0	0,0	1,0
WG_2	0,0	0,1	0,9
WG_3	0,0	0,2	0,8
WG_{13}	0,1	0,1	0,8
WG_{15}	0,1	0,3	0,6

Therefore, using the defined 67 sets of weights, the calculated flattening factors related to the five power demand curves defined in Figure 2 are shown in Figure 4. The main effects of the weight values can be deduced from this figure. Firstly, it must be pointed out that it has not been found a unique set of weights that allow the best power demand curve flattening identification. Nevertheless, it must be remarked that there are some sets of weights that should not be used because the obtained FF would be wrong. Specifically, the next sets of weights should be avoided to prevent misleading results:

- 5, 6, 15, and 23: These configurations provide almost identical flattening factor values for the four non-ideal power demand curves.
- 1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 13, and 14: These configurations provide almost the same flattening factor results for curves 3 and 5. Some of these configurations even provide a better FF result for curve 3 than for curve 5.

V. CONCLUSIONS

This paper has evaluated in detail the influence of the weighting parameters used to assess the flattening degree of the power demand curve. A real power demand profile and several modifications, as well as an ideal flat demand curve, have been used. A wide range of sets of weights have also been considered.

After the tests carried out, interesting conclusions have been achieved:

- The ideal power demand curve, which is described by a constant demand at each hour, provides a flattening factor value equal to 1. This statement is valid when the sum of the three weights is equal to 1. Therefore, the sum of the three weights must be always equal to 1 in order to obtain valuable results.
- It has been proven that the assessment of the demand curve flattening depends on the shape of the profile. This means that profiles with identical shape will generate the same flattening factor value. In fact, this is a necessary requirement to define a suitable demand curve flattening method.
- It has not been found a unique set of weights that allow the best flattening factor value. However, there have been detected several sets of weights that cannot be used because misleading results would be obtained in this case.

Finally, based on the equation to assess the flattening of the power curve proposed and taking into account the different motivations that may have each Distribution System Operator (DSO) utility, several weight groups could be used.

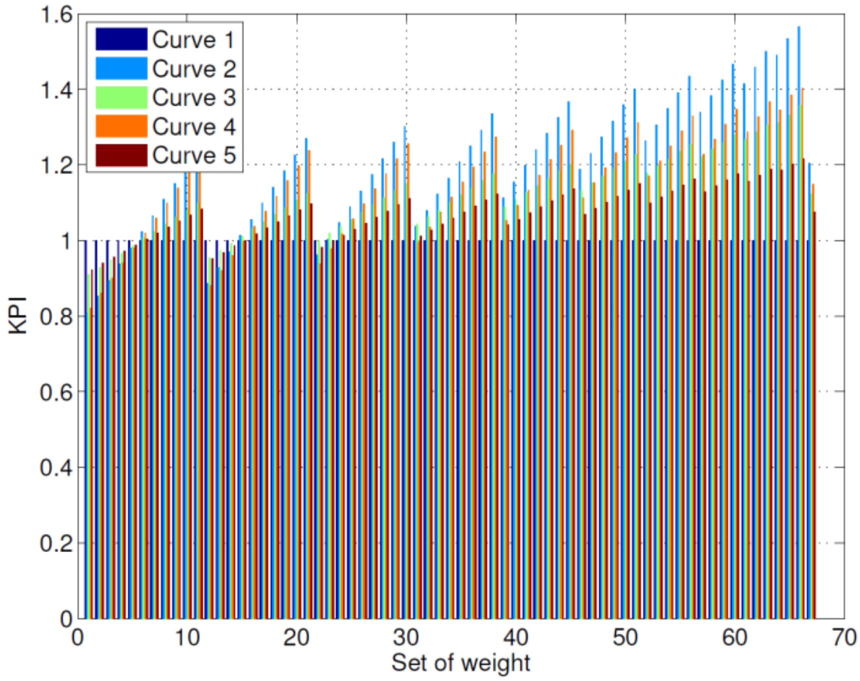

Figure 4. Flattening factors obtained in the five curves with 67 sets of weights (WG).

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