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Construction of the hourly load curves and detecting the annual peak load of future Syrian electric power demand using bottom-up approach

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A B S T R A C T

A comprehensive analysis has been carried out to calculate the hourly electricity demand and the load factors (LF) of the various consumption sectors, construct the load duration curves (LDC) and predict the annual peak load at final and secondary levels with the ultimate task of formulating the expansion plan of future generation system. For this purpose the actual hourly electricity demand (distributed by day types and seasons) of selected typical clients representing the consumption behaviour of household, service, transport and industry sectors in the base year have been collected and evaluated. Starting from these data and using the reference scenario results of future electricity demand projections – in term of annual demand and relative shares of consumption sectors, the future annual LDC's and the total peak load for the next three decades have been constructed using the bottom-up approach MAED_EL. The results indicate that the current residential behaviour of Syrian power system will shift in the reference scenario more and more to the typical industry behaviour characterized by higher load factors. In the study period 1999–2030 the LF will increase from 0.64 to 0.71 and the peak load will grow annually at average rates of 5.2% in the reference scenario.

1. Introduction

In a former study the Syrian long-term energy and electricity demand had been analysed for the period 1999–2030 using the end-use approach [1]. Starting from the base year final energy consumption distributed by energy forms and consumption sectors, the future energy and electricity demand had been projected according to three different scenarios reflecting the possible future demographic, socio-economic and technological development of the country. These development scenarios were constructed to cover a plausible range, in which future evolution factors affecting energy demand are expected to lie. The first is a high economy scenario (HS) representing the reference case, which is characterized by high GDP (gross domestic product) and moderate improved technologies in the various consumption sectors. The second is an energy efficiency scenario (ES), which is identical to HS in all main parameters except these relating to the efficiency improvements and conservation measures. The third is a low economy scenario (LS) with low GDP growth and less technology improvements in the consumption sectors. The results of this analysis showed that the final electricity demand of about 16.7 TWh in the base year will grow annually at average rates of 5.5%, 5% and 3.4% for the HS, ES and LS, respectively.

This work completes the previous analysis and deals with the projection of Syrian future hourly load curve that reflects the change in both amount and behaviour of electricity consumption of various consumption sectors [2,3]. In contradiction to other energy forms the additional requirement in analysing the future electricity demand – represented by hour to hour estimation of expected future consumption – arises from the special nature of electricity as energy form with very limited and costly storage ability. Consequently, the analysis includes the identification of hourly electric load by sector of consumption over the year. This required the construction of annual hourly load curve with the ultimate purpose of detecting the annual peak load that dictates the required total installed capacity of the generation system.

The applied bottom-up approach of MAED_El relies on breaking down the hourly electricity demand by sector of consumption. The hourly electricity demand (corresponding to hourly load curve) of each sector is reconstructed by identification of the hourly demand of selected typical clients (end-user) representing the consumption behaviour of the whole sector. Finally, the aggregation of the hourly electricity demand of all end-users by considering their relative share of consumption enables the reconstruction of total hourly load curve of the country during the year. This approach allows a realistic projection of the future hourly load curve and consequently the annual peak load as the variation of electricity demand can be reflected as result of the future shift between the

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consumption sectors following the socio-economic and technological development of the country.

The results of this analysis in term of hourly load curves and peak loads during the years of the study are usually needed for further analysis dealing with the development of future optimal expansion plan of the electricity generation system [4,5].

2. Methodological approach

To analyse the future development of the Syrian energy and electricity demand the computer program MAED (model for analysis of energy and electricity demand) has been applied. The general approach of MAED relies upon the end-use methodology that was originally developed at IEJE of the University of Grenoble and known as MEDEE. Respecting the general structure of MEDEE the International Atomic Energy Agency (IAEA) developed the present MAED model by introducing important modifications concerning the parameters required to be specified as input data, the equations used for calculating energy demand of some sectors, and some additional modules dealt with the analysis of hourly electricity consumption to construct the so called load duration curve of the power system [6]. The program MAED consists of two modules. The first is MAED_D which was already applied to project future sectorial final energy and electricity demand [1]. The second module MAED_EL (hourly electric power demand) has been developed to convert the annual electricity demand for each economic sector – predicted in MAED_D – to the hourly electricity demand during the year. This module considers four economic sectors in respect of industry, transport, households and services and six clients for each of these sectors to estimate the hourly distribution of annual electricity demand.

Various modulation factors are used to calculate the hourly demand from the annual electricity demand. The modulation factors characterize the changes in the electricity consumption with respect to the average electricity consumption during a year, a week or a day. The variation of electricity load of a given sector by hour, day and week is characterized by a set of modulation coefficients that are defined for 24 h in a day, by type of days in a week and for each week in a year [6].

2.1. Growth trend coefficient T(I)

In order to come to a standard day, the first correction to be made corresponds to the general trend of the growth of electricity consumption during the year. This is represented by a "deflator" which is calculated on a weekly basis (with a total of 53 values in the year), so that the deflator of the gross electricity consumption (i.e. the growth trend coefficient) for week "*I*" is

$$T(I) = \left(1 + \frac{\text{Growth}}{100}\right)^{\frac{I-26.5}{53}} \tag{1}$$

Growth is the average annual growth rate of electricity demand of the current sector between the previous and the current year which is obtained from MAED_D.

2.2. Seasonal coefficients K(I)

They describe the changes in the level of electricity consumption owing to the various seasons of the year on a weekly basis

$$K(I) = \frac{\text{Week}(I)_{\text{consumption}} \times T(I)}{\frac{1}{53}\sum_{1}^{53}\text{Week}(I)_{\text{consumption}} \times T(I)} \tag{2}$$

I = 1..53: number of weeks during a year.

2.3. Daily coefficients for day type P(I, ID)

They describe the changes in the level of electricity consumption owing to the type of day being considered (i.e. working day, weekends, special holidays etc.)

$$P(I, ID) = \frac{\text{Day}(ID)_{\text{consumption}} \text{ of week}(I)}{\text{average day in week}(I)_{\text{consumption}}} \tag{3}$$

ID = 1,. . .,7: days of a week.

2.4. Hourly coefficients for day type

They describe the hourly variation of electricity consumption during a particular day type

$$\text{LCOEF}(L, J, IS, ID) = \frac{HE(L, J, IS, ID)}{\text{EAHE}(J, IS, ID)} \tag{4}$$

where
L = 1,. . ., 24 (hour of day)
J = 1,. . ...., 6 (client of the sector)
IS = 1,. . .., 5 (max. four normal seasons + special season)
ID = 1,. . .., NTD (typical weekdays for daily load curve definition)
whereas

- o *HE (L,J,IS,ID):* Electricity consumption in hour *L* of the typical day *ID* in sector *J* and season *IS*. This value is available from the statistical data.
- o EAHE $(J, IS, ID) = \frac{\sum_{L=1}^{24} HE(L,J,IS,ID)}{24}$: Electricity consumption in an equivalent average hour in typical day *ID* in sector *J* and season *IS*.

In addition to the hourly variation of electricity demand *LCOEF* in Eq. (4), each client type (in a consumption sector) has a weight (share of total sector consumption) in each day type and for each season that is equal to *LCONT*. The aggregated hourly coefficients *LCS* of the sector for each season (*IS*) can be given by summation over all clients as follow:

$$LCS_{IS}(L, ID) = \sum_{J=1}^{6} LCONT_{IS}(J, ID) \cdot LCOEF_{IS}(L, J, ID)$$

LCONT and *LCOEF* values are given as input data for the base year. If the user does not want to change these coefficients for a future year, he may repeat the same coefficients as for the previous year.

Having identified all above-mentioned coefficients, the total number of equivalent working days for current year and sector is given as follows (see Eq. (1)–(3)):

$$N = \sum_{M=1}^{NODAYT} P(I, ID) * K(I) * T(I)$$

where *NODAYT* is the total number of days in the year, -*ID*- stands for day type and -*I*- for the week number of calendar day *M*.

Thus, the energy consumption of the sector in the equivalent average working day

$$EWDS = ENERGY/N$$

where *ENERGY* is the annual electricity consumption of the current sector in the current model year given from the final electricity demand projection [1].

The total electricity consumption of the current sector for the calendar day-M-of current year is given by: $E(M) = EWDS \cdot K(I) \cdot T(I) \cdot P(I, ID)$.