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Representing Load Shifting Demand-Response in TIMES

Proposal for TIMES enhancement by:
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1 INTRODUCTION

Dr. Kathleen Vaillancourt from ESMIA has pointed out that there are some energy system model generators (e.g. ETEM-SG), which include an explicit Demand Response representation by implementing simple demand shifting equations. She suggested that a similar representation would be useful to have implemented into TIMES. Moreover, Dr. Chris Yang from UC Davis requested already in 2015 help for defining load shifting constraints for demands in their TIMES model.

It is indeed quite possible to manually formulate demand shifting equations in TIMES and thus make use of a demand response representation, just by introducing a process for that purpose and then defining user constraints for the process flows. While that gives the user complete control over the equations, in many cases it might still be more convenient to have dedicated model equations implemented internally in TIMES for this purpose, such that simply by defining one or two special-purpose input parameters for a process, the process will then act as a load shifting technology for a given demand associated with it.

Therefore, a simple formulation for a basic load shifting functionality is proposed in this note, along the lines of the previously-mentioned ETEM-SG and the earlier request by Chris Yang, to be considered for implementation in the TIMES model generator. For background information, the description for the simple ETEM-SG representation is given on the page 2.

The very simple demand response representation of the ETEM-SG does not involve any processes, but in the context of TIMES, it would seem most convenient to let the user introduce a process for enabling the load shifting of each demand, or each final electricity commodity, or a group thereof. Following this design approach, the user would thus optionally also be able to define investment costs, fixed O&M cost and variable costs for the demand shifting operation. These could reflect e.g. the costs of the smart real-time control systems needed for load shifting, and/or the additional cost from load shifting perceived by the consumers.

The proposed design for TIMES is given on pages 3 – 4.

Modeling Energy and Technology Choices in Smart Regional Energy Systems

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3.1 Extending ETEM to Demand-Response

The time-slices encode the dynamics of the energy system during a day. The demands for services such as heating and transport are therefore specified for every period t and then allocated to the time-slices s through a parameter called frac_dem: frac dem(D, t, s) is the share of demand D allocated to time-slice s during period t. The frac_dem parameter thus obeys:

$$\sum_{s \in S} frac\_dem(D,t,s) = 1, \quad \forall t$$

In other words, the frac_dem parameter serves as a representation of the shape of the load curve. In order to allow the energy system to adapt to pricing signals, the frac_dem parameter has to be promoted to a variable, VAR_frac_dem. Due to the way the frac_dem parameter enters the equations of ETEM, we can promote it to a variable while staying in the realm of linear programming.

Of course, further constraints have to be enforced.

Additional constraint 1

$$\sum_{s \in S_i} VAR\_frac\_dem(D,t,s) = \sum_{s \in S_i} frac\_dem(D,t,s), \quad \forall t,\ i = 1,\ldots,NS$$

where the S_i's are the subsets of time-slices in each season i = 1,…,NS. For example, S_1 could be for winter, S_2 for summer and S_3 for intermediate. These constraints ensure that the entirety of the demand is met and forbid cross-seasonal load shifting.

Additional constraint 2

$$\begin{aligned}
&(1 - frac_dem_dev(D,t,s)) \times frac_dem(D,t,s) \\
&\quad \le VAR_frac_dem(D,t,s) \qquad\qquad \forall (t,s) \\
&\quad \le (1 + frac_dem_dev(D,t,s)) \times frac_dem(D,t,s)
\end{aligned}$$

where the frac_dem_dev(D,t,s) parameter quantifies the allowed deviation from the nominal value denoted by frac_dem(D,t,s). This parameter can depend on t since the share of the demand can be shifted may evolve due to the progressive penetration of smart technologies.

In order to estimate the parameter frac_dem_dev(D, t, s), we proceed as follows. We first extract the value of frac_dem(D, t, s) from the load curves. One then identifies the share of the demand that may be shifted across time and calibrate frac_dem_dev(D, T, s). Finally, we assume a learning curve dictates the evolution of frac_dem_dev(D, t, s). Several methods can be used to estimate the share of the demand that can be shifted. For example, a survey has been designed and rolled out in the French-speaking part of Switzerland to find out what could be the acceptance of demand response for residential electricity. The survey considered also the acceptance of using an electric car as a mean for grid storage. For other flexible demands (heating, warm water heating, some industrial processes), one can exploit estimates from the literature.

2 DESIGN FOR TIMES IMPLEMENTATION

2.1 Basic functionality

Because in TIMES introducing new variables for the demands by time-slice would require redesigning all the commodity balance equations, probably an easier add-on type approach would be a demand shifting process, where the input / output flows would represent demand shifting upwards and downwards. In addition, this approach appears more convenient also because then the user would also be able to define investment costs, fixed O&M cost and variable costs for the demand shifting operation, and could easily refer to the process activity and capacity variables in user constraints, if needed. Preventing load shifting in either direction in any individual time-slices would also be easy by bounding the corresponding process flows to zero using STGIN_BND/STGOUT_BND.

In TIMES, the shape of the load curve for each demand D is defined by the COM_FR attribute:

$$\sum_{s \in S} COM\_FR(r,t,D,s) = 1, \quad \forall (r,t) \tag{1}$$

In the proposed design, the user would thus need to define a storage process P for the demand shifting operation of a demand D, such that the D is both an input and an output (or more generally, the input could also be a second commodity upstream). The user would additionally only need to define the proportional limits for the allowed demand shifting, by using a new attribute STG_SIFT(r,t,p,c,s). The load shifting constraints would then be automatically generated for the process, imposing first the following seasonal balances:

$$\sum_{s \in S_i} VAR\_IN(r,t,p,D,s) = \sum_{s \in S_i} VAR\_OUT(r,t,p,D,s), \quad \forall (r,t),\ i = 1,\ldots,NS \tag{2}$$

where the Si's are the subsets of time-slices in each season i = 1,...,NS. For example, S_1 could be for winter, S_2 for summer and S_3 for intermediate. These constraints ensure that the entirety of the demand is met and forbid cross-seasonal load shifting.

The TIMES model generator would aggregate the final useful energy demand automatically into the VAR_COMPRD variables, which satisfy the original load curve (apart from any the effect of demand elasticity). Therefore, the constraints for the maximum allowed deviations from the exogenous nominal demand fractions can in this case be formulated as follows:

$$\begin{aligned} &VAR\_OUT(r,t,p,D,s) \le STG\_SIFT(r,t,p,D,s) \times VAR\_COMPRD(r,t,D,s) \\ &VAR\_IN(r,t,p,D,s) \le STG\_SIFT(r,t,p,D,s) \times VAR\_COMPRD(r,t,D,s) \quad \forall (r,t,s) \end{aligned} \tag{3}$$

Note that we have assumed the allowed deviation from the original load curve VAR_COMPRD(r,t,D,s) to be symmetrical. If considered useful, asymmetries could also be introduced in a straightforward way.

The activity of the storage process is proposed to be defined by the discharge flow, and so the capacity would correspond to the maximum amount of load displaced.

2.2 Advanced functionality

The user would optionally also be able to define balance constraints like (2) over user-defined sets of adjacent time-slices. In the design suggested, the TIMES input attribute ACT_TIME(r,t,p,'N') = N would be made available for defining additional equations forcing the total demand in each set of time-slices within N consecutive hours to be greater than or equal to the original demand during that time window. This option would be mostly useful for models that do not employ the default convention of daily cycles in TIMES, but use some longer DAYNITE cycles, such as the 8760 hours of a full year. For example, one could thus constrain the demand in each consecutive 24 hours to be at least the original demand before load shifting.

Moreover, the TIMES input attribute ACT_TIME(r,t,p,'FX') = M could also be made available for defining additional constraints, forcing all the shifted loads to be met within a specified time of either advance or delay. The time is specified as the number of hours M, by which the shifted load can be either postponed or met earlier. Note that for the compactness of the formulation, we have assumed the allowed time of advance or delay to be symmetrical around the shifted load. If considered worthwhile, asymmetries between advances and delays could also be introduced.

Finally, when using the option of constraining the time to meet the shifted loads in advance or delay, as described above, the user would also have the option of defining costs on the shifting of one unit of demand load by one hour, forward (UP) and backward (LO). The time-integral of each shifted load would then be multiplied by the unit cost specified. For specifying the unit costs, the ACT_CSTRMP(r,t,p,bd,cur) attribute (bd=UP/LO) could be used.

In summary, according to the proposed design the following constraints could be modelled for the load-shifting processes:

- Standard capacity-activity equations;
- Seasonal balance equations (Eq. 2 above);
- Maximum allowed fractions of loads shifted (Eq. 3 above);
- User-defined balance constraints over sets of adjacent time-slices;
- Maximum allowed time to meet the shifted loads in advance or with delay;
- Capacity bounds, activity bounds, flow bounds.

In summary, according to the proposed design the following costs could be modelled for the load-shifting processes:

- Activity costs (cost on the discharge flow);
- Flow costs (cost on the charge and/or discharge flow);
- Capacity cost (cost on the discharge load capacity);
- Fixed O&M cost (cost on the discharge load capacity);
- Cost of shifting of one unit of demand load by one hour, forward (UP) and/or backward (LO).

2.3 Usage notes

Requirements:

- The user must introduce a load shifting process for each useful demand or final energy demand commodity (or a group of such) for which load shifting is to be enabled. The process must be a DAYNITE level storage process having the demand as an output. The input should normally be the same commodity, but an upstream electricity commodity could also be used, if the demand commodity is at the ANNUAL level. For groups of demands the feature is still only experimental.

Summary of input parameters specific to load shifting:

- STG_SIFT(reg,year,prc,com,ts) = <fraction> :
  Defines process prc as a load shifting process, and limit the load shifting of demand com in timeslice ts to at most the fraction specified as the parameter value. The parameter is by default fully inter-/extrapolated and levelized.
  If com is an output demand commodity, the limit is applied to the shifting of that demand in each timeslice on the DAYNITE level; if com='ACT', the limit is applied to the total shifting during each timeslice above the DAYNITE level (and thus to the total shifting within each representative day).
- ACT_TIME(reg,year,prc,lim) = <N> :
  - lim = 'N' : Limit the total demand in each set of time-slices within N consecutive hours to be greater than or equal to the original demand during that time window.
  - lim = 'FX' : Require the shifted loads to be met within a specified time (N hours) of either advance or delay.
  - lim = 'LO'/'UP': Require the shifted loads to be met within a specified time (N hours) advance ('LO') or delay ('UP').

  The parameter is by default fully inter-/extrapolated.
- ACT_CSTRMP(reg,year,prc,bd,cur) = <value> :
  Defines a cost on the shifting of one unit of demand load by one hour, forward (bd=UP) or backward (bd=LO). The parameter is by default fully interpolated and extrapolated.

Remark: Note that the ACT_CSTRMP costs are per hour, and depend also on the load unit (capacity unit of the process). Thus, if the load unit is GW and the currency unit is MUSD, defining a value of 1 would already mean a relatively high cost of 1 USD per kWh.