TIMES Version 3.4 User Note

TIMES Grid Modeling Features

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Foreword

This User Note contains the documentation for the implementation and usage of the new grid modeling features in the TIMES model generator.

The document is divided into four chapters. Chapter 1 contains an introduction, and Chapter 2 presents a brief description of the mathematical formulation, on which the implementation is based. Chapter 3 contains the description of the GAMS implementation of the new elements, along with the input parameters, variables, and equations that have been added to the TIMES model. Finally, Chapter 4 constitutes a brief User's Reference Manual for the grid modeling features in TIMES.

This documentation is a supplement to the complete documentation of the TIMES model generator.

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1. INTRODUCTION

The specific grid modeling features of TIMES are intended for modelers who wish to include basic characteristics of electricity grids in their energy system models. This implies that at least a simple representation of the geographical and spatial distribution of generators, consumer loads and the transmission network is included in the reference energy system.

The grid modeling features can be useful, for example, for analyzing potential bottlenecks in the electricity transmission system, and for evaluating the impacts of the integration of large amounts of variable renewable generation in the system. Such analyses could thus be utilized for giving an indication of the enforcements and new investments that would be needed in various parts of the main grid under different future scenarios.

The specific grid modeling features include the following components:

- Linear DC power flow equations;

- A facility for including a grid representation in the model by using an add-on approach with automated allocation of generation and demand to grid nodes;

- Simplified N–1 security constraints;

- New parameter for defining costs on specific grid flows.

2. MATHEMATICAL FORMULATION

2.1 DC Load Flow Equations

The general form of the DC load flow equations can be written as follows:

For every grid node i:

$$G_i - L_i = \sum_{j=1}^{M} P_{i,j} \tag{1}$$

And for each grid connection i,j between nodes i and j we have the relationship:

$$P_{i,j} = B_{i,j}(\delta_i - \delta_j) = (\delta_i - \delta_j)/X_{i,j} \tag{2}$$

where:

   M = the number of nodes connected with node i
   G_i = active power injected into node i by generators
   L_i = active power withdrawn from node i by consumer loads
   P_{ij} = branch flow from node i to node j
   B_{ij} susceptance of the branch connecting nodes i and j
   X_{ij} reactance of the branch connecting nodes i and j
   δ_i voltage phase angles of node i with respect to a reference angle

Equation (2) has been implemented into TIMES using the following formulation. For each pair of two grid nodes i in region r and j in region $r2$ connected by some grid lines p by TOP(r,i,r2,j,p), we have the following condition (in simplified terms):

$$\sum_{p \in TOP(r,i,r2,j,p)} VAR\_IRE(r,v,t,p,i,s,EXP) - VAR\_IRE(r,v,t,p,i,s,IMP) = \tag{3}$$
$$GR\_ADMIT(r,t,i,r2,j) \cdot (VAR\_DELTA(r,t,i,s) - VAR\_DELTA(r2,t,j,s))$$

where:

- VAR_IRE(r,v,t,p,n,s,ie) = flow variable for inter-regional trade process p in region r node n and timeslice s

- VAR_DELTA(r,t,n,s) = new variable representing voltage phase angle of node n in region r and timeslice s

- GR_ADMIT(r,t,n,r2,m) = internal parameter representing the susceptance of the grid connection between node n in region r and node m in region $r2$.

The internal susceptance parameter *GR_ADMIT* can be calculated form the user input parameter *PRC_REACT* as follows:

$$GR\_ADMIT(r,t,i,r2,j) = \left(\sum_{\substack{p \in \{TOP(r,i,r2,j,p) \cap RTP\_VARA(r,t,p)| \\ PRC\_REACT(R,T,P)>0\}}} \frac{1}{PRC\_REACT(r,t,p)} \right) \quad (4)$$

where:

- PRC_REACT(r,t,p) = input parameter specifying the reactance of line *p*

- TOP(r,p,c,io) = set of 4-tuples defining the topology of process *p* in region *r* in terms of commodities *c* and IN/OUT indicator *io*;

- RTP_VARA(r,t,p) = set of 3-tuples indicating availability of process in period *t*

2.2 Allocation of Generation and Load to Grid Nodes

In the context of TIMES, it may be desirable to be able to model the electricity grid as an ***add-on***, without changing the original structure of the model. Therefore, we need to determine the set of necessary equations for calculating the grid injections by generation units and the grid loads from customer demands in each node and timeslice of TIMES.

Within each region, the generation and load can be allocated to the grid nodes in that region, based on linear allocation equations.

The equations for allocating electricity generation to the grid nodes are defined for each grid node ***i***, each generated electricity commodity ***com*** and each DAYNITE timeslice ***s*** in region ***r***, as follows (simplified formulation):

$$VAR\_GRIDELC(r,t,com,i,s,OUT) =$$
$$\quad (5)$$

$$\sum_{\substack{c \in ELG(r), \\ p \in PRC(r)}} \left(\begin{array}{l} GR\_GENMAP(r,p,type) \cdot GR\_GENFR(r,t,i,type) \cdot \\ TOP(r,p,c,OUT)*VAR\_FLO(r,v,t,p,c,s) \end{array} \right) +$$

$$\sum_{\substack{c \in ELG(r), \\ p \in PRC(r)}} \left(\begin{array}{l} GR\_GENMAP(r,p,type) \cdot GR\_GENFR(r,t,i,type) \cdot \\ TOP(r,p,c,OUT)*VAR\_SOUT(r,v,t,p,c,s) - \\ TOP(r,p,c,IN)*VAR\_SIN(r,v,t,p,c,s) \end{array} \right) +$$

$$\sum_{\substack{c \in ELG(r), \\ p \in PRC(r)}} \left(\begin{array}{l} GR\_GENMAP(r,p,type) \cdot GR\_GENFR(r,t,i,type) \cdot \\ RPC\_IRE(r,p,c,IMP)*VAR\_IRE(r,v,t,p,c,s,IMP) - \\ RPC\_IRE(r,p,c,EXP)*VAR\_IRE(r,v,t,p,c,s,EXP) \end{array} \right)$$

where:
- VAR_GRIDELC(r,t,c,n,s,OUT) = new variable representing generation of electricity commodity *c* to node *n* in region *r* and timeslice *s*;

- VAR_FLO(r,v,t,p,c,s) = flow variable for process *p* in region *r* node *n* and timeslice *s*;
- VAR_SOUT(r,v,t,p,c,s) = storage output flow variable for process *p* in region *r* node *n* and timeslice *s*;
- VAR_SIN(r,v,t,p,c,s) = storage input flow variable for process *p* in region *r* node *n* and timeslice *s*;
- VAR_IRE(r,v,t,p,c,s,ie) = inter-regional exchange flow variable for process *p* in region *r* node *n* timeslice *s* and exchange direction indicator *ie*.
- GR_GENMAP(r,p,type) = user input parameter specifying the mapping of processes *p* to generation unit types *type* in region *r*;
- GR_GENFR(r,t,n,type) = user input parameter specifying the fractions of generation unit types *type* to be allocated to grid nodes *n* in region *r*;
- TOP(r,p,c,io) = set of 4-tuples defining the topology of process *p* in region *r* in terms of commodities *c* and IN/OUT indicator *io*;
- ELC(r), PRC(r) = sets of electricity generation commodities and processes in region *r*, respectively.

In an analogous manner, the total load of consumed electricity commodities can be allocated to each grid. The equations for allocating electricity demand to the grid nodes are generated for each node *i* and each DAYNITE timeslice *s* in region *r*, as follows (simplified formulation):

$$\sum_{com \in ELG(r)} VAR\_GRIDELC(r,t,com,i,s,IN) = \tag{6}$$

$$\sum_{c \in ELD(r)} \left(\begin{array}{l} GR\_ENDFR(r,t,i,c) \cdot \\ \left(\begin{array}{l} (1 + GR\_ENDFR(r,t,c,c)) \cdot VAR\_COMPRD(r,t,c,s) - \\ GR\_ENDFR(r,t,c,c) \cdot \sum\limits_{\substack{j \in N(r), \\ c \in ELG(r)}} VAR\_GRIDELC(r,t,c,j,s,IN) \end{array} \right) \end{array} \right)$$

$$\sum_{com \in ELG(r)} VAR\_GRIDELC(r,t,com,i,s,IN) = \tag{7}$$

$$GR\_DEMFR(r,t,i,s) \cdot \left(\sum_{\substack{j \in N(r), \\ c \in ELG(r)}} VAR\_GRIDELC(r,t,c,j,s,IN) \right)$$

where:
- VAR_GRIDELC(r,t,c,n,s,IN) = new variable representing demand of electricity commodity *c* from node *n* in region *r* and timeslice *s*;
- VAR_COMPRD(r,t,c,s) = variable for total production of commodity c in region *r* and timeslice *s*;
- GR_ENDFR(r,t,n,com) = user input parameter specifying the fractions of electricity demand commodities *com* to be allocated to grid nodes *n* in region *r*;

- GR_ENDFR(r,t,com,com) = user input parameter specifying the estimated transmission losses of electricity demand commodity *com* in region *r*;
- GR_DEMFR(r,t,n,ts) = user input parameter specifying the fractions of total electricity demand to be allocated to grid nodes *n* in region *r* and timeslice *ts*;
- ELG(r) = set of electricity generation commodities in region *r*;
- ELD(r) = set of sectoral electricity demand commodities in region *r*;
- N(r) = set of grid nodes in region *r*.

Equation (6) is applied in region *r* only when the sectoral demand allocation approach is used, i.e. the parameter GR_ENDFR has been specified for region *r*. Equation (7) is applied in region *r* only when the total demand allocation approach is used, i.e. only the parameter GR_DEMFR has been specified for region *r*.

In addition to the equations presented above for allocating the generation and demand to the grid nodes, the VAR_GRIDELC variables must also satisfy the following conditions:

$$VAR\_GRIDELC(r,t,c,i,s,IN) \leq VAR\_GRIDELC(r,t,c,i,s,OUT),$$
$$if\ GR\_GENLEV(r,c) = 2 \tag{8}$$

$$VAR\_GRIDELC(r,t,c,i,s,IN) = VAR\_GRIDELC(r,t,c,i,s,OUT),$$
$$if\ GR\_GENLEV(r,c) = 3 \tag{9}$$

where:
- GR_GENLEV(r,c) = user input parameter specifying the grid connection characteristic of electricity generation commodity *c* in region *r*, as follows:
    - GR_GENLEV(r,c) = 1 means that the commodity can be injected to the grid and withdrawn from the grid in a fully flexible manner;
    - GR_GENLEV(r,c) = 2 means that the commodity can be net-injected to the grid but can not be net-withdrawn from the grid (see (8));
    - GR_GENLEV(r,c) = 3 means that the commodity can neither be net-injected to the grid nor net-withdrawn from the grid, i.e. all local production of *c* at any grid node must be consumed locally at that node (see (9));

In order to complete the integration of the new grid variables into the original model, the VAR_GRIDELC variables must also be included in the commodity balances and peak equations of the electricity generation commodities, and in the commodity balances of the grid nodes. The terms to be included are the following:

$$\sum_{i \in N(r)} VAR\_GRIDELC(r,t,com,i,s,OUT) - VAR\_GRIDELC(r,t,com,i,s,IN) \tag{10}$$

$$\sum_{com \in ELG(r)} VAR\_GRIDELC(r,t,com,i,s,IN) - VAR\_GRIDELC(r,t,com,i,s,OUT) \tag{11}$$

In the commodity balances of the electricity generation commodities *com*, the term (10), multiplied by COM_IE, is added on the demand side, whereas in the peaking constraints, the term (10) is added on the production side with an opposite sign. In the commodity balances of the grid nodes the term (11) is added on the demand side.

Remark: Within TIMES, both the nodal generation and nodal load variables are internally represented in terms of energy. However, these can be easily converted into terms of power by the following simple relationships:

$$VAR\_GRIDELC(r,t,c,i,s,io) = \frac{VAR\_GRIDELC(r,t,c,i,s,io)}{G\_YRFR(r,s)} \tag{12}$$

where:
- G_YRFR(r,s) = duration of timeslice *s* as fraction of a year.

2.3 Simplified N-1 Security Constraints

For N–1 security considerations, we want to state that in each region the following condition holds:

$$\left| GEN(r,t,s) - LOAD(r,t,s) \right| \le \alpha \cdot PMAX(r,t) \tag{13}$$

where:
- GEN(r,t,s) = total injection into the grid in region *r*;
- LOAD(r,t,s) = total withdrawal from the grid in region *r*;
- PMAX(r,t) = total capacity of intra-regional lines between *r* and other regions.

This constraint can be written in terms of TIMES variables as follows. For each region r, timeslice s and exchange indicator ie, we require that

$$\sum_{\substack{com\in ELG(r)\\ i\in N(r)}} VAR\_GRIDELC(r,t,com,i,s,IN) - VAR\_GRIDELC(r,t,com,i,s,OUT) \tag{14}$$

$$\le GR\_XBND(r,t) \cdot G\_YRFR(r,s) \cdot$$
$$\sum_{\substack{(r2,c,p\in)TOP\_IRE(r2,c,r,com)\\ v\in RPT\_VINTYR(r,v,t,p)}} \begin{aligned} &COEF\_CPT(r,v,t,p) \cdot PRC\_CAPACT(r,p) \cdot \\ &(VAR\_CAP(r,v,t) + NCAP\_PASTI(r,v,p)) \end{aligned}$$

$$\sum_{\substack{com\in ELG(r)\\ i\in N(r)}} VAR\_GRIDELC(r,t,com,i,s,OUT) - VAR\_GRIDELC(r,t,com,i,s,IN) \tag{15}$$

$$\le GR\_XBND(r,t) \cdot G\_YRFR(r,s) \cdot$$
$$\sum_{\substack{(r2,c,p\in)TOP\_IRE(r,com,r2,c)\\ v\in RPT\_VINTYR(r,v,t,p)}} \begin{aligned} &COEF\_CPT(r,v,t,p) \cdot PRC\_CAPACT(r,p) \cdot \\ &(VAR\_CAP(r,v,t) + NCAP\_PASTI(r,v,p)) \end{aligned}$$

where:

- GR_XBND(r,t) = user input parameter α;
- G_YRFR(r,s) = duration of timeslice *s* as fraction of a year;
- COEF_CPT(r,v,t,p) = capacity transfer coefficient for vintage *v*;
- PRC_CAPACT(r,p) = conversion from capacity to activity units;
- VAR_NCAP(r,v,p) = newly installed capacity of process *p* and vintage *v*;
- NCAP_PASTI(r,v,p) = past installed capacity of process *p* and vintage *v*.

2.4 Costs on Grid Flows

The TIMES implementation includes also a new cost attribute COM_CSTBAL, which can be used for defining cost coefficients on different grid flows. As the mathematical formulation of including these cost coefficients should be quite obvious, the detailed formulation of the corresponding new objective function component *OBJBAL* is omitted here, and only a cursory formulation is presented:

$$
VAR\_OBJ(r, OBJBAL, cur) =
\sum_{n,t,s,type} \left(\begin{array}{c} COM\_CSTBAL(r,t,n,s,type,cur) \cdot COEF\_PVT(r,t,cur) \cdot \\ [\text{relevant flow variable expression}] \end{array} \right)
\tag{16}
$$

where:

- VAR_OBJ(r,OBJBAL,cur) = new component for the TIMES objective variable VAR_OBJ;
- OBJ_CSTBAL(r,t,n,s,type,cur) = user input parameter specifying a cost of type *type* on grid flows at node *n* in region *r*, in timeslice *s* and with currency *cur*;
- COEF_PVT(r,t,cur) = present value coefficient for period t in region *r* and with currency *cur*.

See the parameter description for more details on using this new cost parameter.

3. GAMS IMPLEMENTATION

3.1 Overview

As discussed in Section 2, certain special facilities have been implemented into TIMES for the modeling of electricity grids and power flows in the transmission system. These features can be useful, for example, for analyzing bottlenecks in the transmission system and integration of large amounts of variable renewable generation in the system, whereby the transmission lines may have to be particularly enforced in certain parts of the grid.

3.2 Parameters

3.2.1 Input parameters

All the parameters for the grid modeling features are available in the VEDA-FE shell, where they may be specified. Most of the new parameters have the prefix '**GR_**' in the GAMS code of the model generator. The parameters are discussed in more detail below:

1. The parameter **PRC_REACT(r,y,p)** can be used for specifying the reactance of transmission line p (unit: relative).

   - For inter-regional lines, the parameter can be defined on either side of the link (if defined on both sides, the maximum value is taken)
   - The parameters also define the lines to be included in the grid topology
   - If zero reactance is specified, the line is included in the grid but is excluded from the power flow equations.

2. The parameter **GR_GENLEV(r,c)** can be used for defining the generation level indicator for generated electricity commodity c:

Table 1. Input parameters for the special TIMES grid modeling features.

Parameter	Description
PRC_REACT(r,y,p)	Reactance of grid transmission line p
GR_GENLEV (r,c)	Grid connection category for electricity generation commodity c
GR_GENMAP(r,p,u)	Mapping of generation technology p to generation of type u
GR_GENFR (r,y,n,u)	Fraction of electricity generation of type u allocated to grid node n
GR_DEMFR (r,y,n,s)	Fraction of total electricity demand allocated to grid node n
GR_ENDFR(r,y,n,c)	Fraction of sectoral electricity demand allocated to grid node n
GR_XBND(r,y)	Maximum power level of net imports to / exports from region r
COM_CSTBAL (r,y,n,s,type,cur)	Cost on specific type of grid flow (energy flow) at node n

- GR_GENLEV(r,c) = 1 means that the commodity can be injected to the grid and withdrawn from the grid in a fully flexible manner;
- GR_GENLEV(r,c) = 2 means that the commodity can be net-injected to the grid but can not be net-withdrawn from the grid (see (8));
- GR_GENLEV(r,c) = 3 means that the commodity can neither be net- injected to the grid nor net-withdrawn from the grid, i.e. all local production of *c* at any grid node must be consumed locally at that node (see (9));

3. The parameter **GR_GENMAP(r,p,u)** can be used for defining the mapping of generating technology p to unit type *u*. Normally, the parameter would have the value 1.

4. The parameter **GR_GENFR(r,y,n,u)** can be used for specifying the fraction of the generation from unit type *u* to be allocated to grid node *n*.

5. The parameter **GR_DEMFR(r,y,n,s)** can be used for defining the fraction of the total demand in timeslice *s* to be allocated to grid node *n*. The parameter is only taken into account in region *r* if no **GR_ENDFR** parameter has been defined for that region.

6. The parameter **GR_ENDFR(r,y,n,com)** can be used for defining in region *r*

    - (1) the fraction of the sectoral demand *com* to be allocated to node *n* (*n≠com*)
    - (2) the approximate transmission losses for the sectoral demand com (*n=com*), as a fraction of the demand level

7. The parameter **GR_XBND(r,y)** can be used for defining the maximum power level of net imports to / exports from region *r* (i.e. total net demand from / net injection to the grid in region *r*), in proportion to the total capacity of the transmission lines between R and other regions (units: fraction).

8. The parameter **COM_CSTBAL(r,y,n,s,type,cur)** can be used for defining a cost for the generation (*type*=PRD), imports (IMP), exports (EXP), net imports (NTX), consumption (CON), or net positive generation (NPG) at node N, optionally differentiated by timeslice *s* (unit: currency unit / energy unit).

3.2.2 Reporting parameters

The energy flows in the grid are reported normally in the reporting parameters for process flows, and the grid node balances in the reporting parameters for commodity balances.

The annual costs related to the new parameter COM_CSTBAL are reported in the CST_COMC reporting parameter and in the variable cost component of the REG_ACOST reporting parameter. The corresponding objective component is reported in the variable cost component of the REG_WOBJ reporting parameter.

Table 2. Variables for the grid modeling features in TIMES.

Variable	Description
VAR_COMAUX(r,t,n,s)	The delta variables for the voltage phase angles.
VAR_GRIDELC(r,t,c,n,s,io)	The variable representing the injection/withdrawal of electricity commodity c to/from grid node n in timeslice s.

3.3 Variables

There are only two sets of new variables introduced in the implementation of the grid modeling features, VAR_COMAUX and VAR_GRIDELC which are shown below in Table 2.

The variables VAR_COMAUX represent the voltage phase angle variables for each grid node, timeslice and period. The new variables VAR_GRIDELC represent the amounts of each electricity generation commodity injected into each of the grid nodes, and the corresponding amounts of these commodities withdrawn from each of the grid nodes. Also these injection/load variables are timeslice and period specific.

As there are thus essentially no other changes to the model variables, the user is referred to Chapter 4 of the TIMES Reference Manual for details on the variables of the model.

3.4 Equations

Below in Table 3 the few new equations related to the grid modeling features are listed and briefly described. The equations include the linear DC power flow equations,

Table 3. Equations for the grid modeling features in TIMES.

Equation	Description
EQ_GR_POWFLO(r,t,n,s,reg,com)	The linear DC power load flow equations for each grid line.
EQ_GR_GENALL(r,t,n,s,cg)	The equations for allocating electricity generation to grid nodes.
EQ_GR_DEMALL(r,t,n,s)	The equations for allocating electricity demands to grid nodes.
EQ_GR_XBND(r,t,s,ie)	The simplified N-1 security constraints for the total amount of imported / exported electricity into / from region r.
EQ_OBJBAL(r,cur)	The equations for the costs on the grid flows, which are summed into a new component of VAR_OBJ.

allocation equations for both electricity generation and demands, and the simplified N–1 security constraints described earlier in section 2.3.

Note that the equation for the augmented final objective function, **EQ_OBJ**, has the same name as in standard TIMES, only the definition of this equation is different when costs have been defined on the flows in the grid by using the **COM_CSTBAL** parameter. Similarly, also the objective variable ObjZ has the same name as in standard TIMES.

3.5 Changes in Model Generator Code

The implementation required only small modifications to the existing code and only one new component in the model generator source code. The new and modified code components are listed in Table 4.

The new source file **powerflo.vda** contains basically all of the new code for the grid modeling features. This file is automatically called from the file equ_ext.vda, if either the parameter PRC_REACT or the parameter COM_CSTBAL has been defined. Also the new variables and equations as well as the additional term in the objective function have been conditionally defined in this file. Finally, the reporting file cost_ann.rpt also conditionally calls the file powerflo.vda whenever the parameter COM_CSTBAL has been defined.

Table 4. New and modified files in the TIMES model generator code.

Added file	Description
powerflo.vda	Declarations, preprocessing and equations for the grid features
Modified file	**Description of changes made**
cal_ire.mod	Conditional addition of grid variable terms to balance equations
mod_vars.mod	Conditional additions to variable declarations
initmty.vda	Declarations for the grid modeling features
init_ext.vda	Initializantions for the grid modeling features
prep_ext.vda	Conditional calling of powerflo.vda for parameter interpolation
pp_prelv.vda	Conditional calling of powerflo.vda for pre-processing
coef_ext.vda	Conditional calling of powerflo.vda for pre-processing
equ_ext.vda	Conditional calling of powerflo.vda for equation definitions
mod_ext.vda	Conditional additions for the model statement
cost_ann.rpt	Conditional calling of powerflo.vda for cost reporting purposes

4. USER'S REFERENCE

4.1 Activating the Grid Equations

The linearized DC power flow equations are automatically activated in TIMES whenever the PRC_REACT parameter is specified for at least one transmission line in some region. However, the activation of the feature can also be done manually by using the following settings in the run file (the trailing comment part starting from '!' should not be included):

    $ SET POWERFLO YES   ! Activate power flow analysis feature

Nonetheless, in any case, the power flow equations are generated only for those lines that have a non-zero value of the parameter PRC_REACT specified.

The automated allocation facilities for the add-on-grid approach are also activated by the corresponding input parameters, but they also require that the grid topology has been defined by using PRC_REACT parameters. Zero values for PRC_REACT can always be used for including lines in the grid but excluding them from power flow equations.

4.2 Defining the Grid

- In general, all grid transmission lines should be bi-directional trade processes (unless only one direction is technically possible);
- All inter-regional transmission line processes should have unique names, but intra-regional processes may utilize the same process names in all regions;
- Grid nodes are represented in TIMES by specific electricity commodities;
- The generation and demand of electricity can be either explicitly modeled for each of the grid nodes, or they can also be automatically allocated to the nodes;
- If the automated allocation of generation and demands to the grid nodes is to be used, the nodes in each region should be defined using completely distinct new commodity names (of type NRG+ELC, at DAYNITE level), e.g. GN1, …, GN4;
- All lines should, in general, have either investment costs defined or PRC_RESID / NCAP_PASTI specified, or both (to avoid arbitrary flows in both directions);
- For any inter-regional line between regions R1 and R2, one should preferably define the PRC_RESID/NCAP_PASTI and investment costs only on either side of the link (either in region R1 or in R2), to have a *single* consistent line capacity;
- For all bi-directional transmission lines, availability factors can also be defined to be direction-dependent by using the NCAP_AFC parameter instead of NCAP_AF:
  - For inter-regional lines, by defining NCAP_AFC both on the traded commodity (for imports) and on NRG (for exports) in the region that has the line capacity;
  - For intra-regional lines, by defining NCAP_AFC on both of the two grid node commodities involved.

4.3 Transmission Losses

- Optional transmission losses can be defined for each transmission line, and should be specified by using a negative IRE_FLOSUM(reg,y,line,n,ts,'IMP',n,'OUT') parameter on the imports into node *n*. In other words, one should not use the IRE_FLO parameter for defining transmission efficiencies, but instead using the IRE_FLOSUM parameter is advised.
- If the allocation methods are used for the generation and demands (see section 4.5), the intra-regional transmission losses have usually been already accounted in the original model. In that case, transmission losses should probably not be added to the intra-regional grid-lines, to avoid double counting of the losses.

4.4 Linear DC Power Flow Equations

- The reactances (inverse of susceptance) for the transmission lines are defined by PRC_REACT(r,y,p). For inter-regional lines, the parameter can be defined on either side of the link (if defined on both sides, the maximum value is taken);
- The reactance parameters also define the lines to be included in the grid topology;
- If zero reactance is specified, the line is included in the grid but is excluded from the power flow equations;

4.5 Allocating Generation and Demands to Nodes

- All electricity generation commodities ***com*** to be included in the allocation of generation must have the GR_GENLEV(reg,com) parameter defined:
    - GR_GENLEV(reg,com)=1 signifies that the commodity can be withdrawn from and injected to the grid in a fully flexible way;
    - GR_GENLEV(reg,com)=2 signifies that the commodity can only be injected to, but not withdrawn from the grid in net terms;
    - GR_GENLEV(reg,com)=3 signifies that the commodity can neither be withdrawn from nor injected to the grid in net terms;
- All electricity generation technologies ***prc*** should be mapped to unit types ***u*** by using the GR_GENMAP(reg, prc, u) parameter (normally with the value 1)
- All unit types should be allocated to the grid nodes ***n*** by using the GR_GENFR(reg, y, n, u) parameter, representing the fraction of the generation of type ***u*** to be allocated to the node ***n*** in region ***reg***;
- The regional demand for electricity can be allocated to the grid nodes in two alternative ways A and B, as follows:
    - A. By allocating the total demand in each timeslice to the grid nodes; or
    - B. By allocating each sectoral electricity demand to the grid nodes.
- If using alternative A, where the total demand in each timeslice ts is to be allocated to each grid node ***n***, one should use the GR_DEMFR(reg, y, n, ts) parameter, representing the fraction of the demand in timeslice ***ts*** to be allocated to the node ***n*** in region ***reg***;

- If using alternative B, where the demand for each sectoral electricity *elcs* is to be allocated to each grid node *n*, one should use the following approach:
  - Use the GR_ENDFR(reg, y, n, elcs) parameter for specifying the fraction of the sectoral demand for *elcs* to be allocated to the node *n* in region *reg*;
  - As the demands usually represent amounts after endogenous transmission losses, one can additionally specify approximate transmission losses for each sectoral demand *elcs* by using the GR_ENDFR(reg, y, elcs, elcs) parameter, representing the amount of losses in proportion to the demand; otherwise transmission losses are allocated to an (arbitrary) single node;
- All the fractional allocation parameters are automatically normalized by TIMES, such that the sum of them over the grid nodes (or unit types) equals to 1.

4.6 Additional Parameters

- Costs on the total generation into grid node *n*, or on the total or net transmission to/from node *n*, can be specified by using the COM_CSTBAL(reg,y,n,s,type,cur) parameter, either differentiated by timeslice *s*, or for all timeslices (*s*=ANNUAL). The *type* can be any of the following:
  - PRD – production (generation into the node)
  - CON – consumption (demand from the node)
  - IMP – transmission into the node from other grid nodes
  - EXP – transmission from the node to other grid nodes
  - NTX – net imports to the node (IMP – EXP)
  - NPG – net <u>positive</u> generation injected into the node ($\text{Max}(0, G_{r,n} - L_{r,n})$)
- The total net imports to and exports from region *reg*, in proportion to the total transmission line capacity between *reg* and other model regions, can be bounded by using the GR_XBND(reg,y) parameter. The bound is an upper bound. As the net exports are equal to the total net injection $G_r - L_r$, the constraints generated are equivalent to the equations $|G(\text{reg},\text{y},\text{s}) - L(\text{reg},\text{y},\text{s})| \leq \text{GR\_XBND}(\text{reg},\text{y}) \cdot \sum P_{max}$ for each year *y* and timeslice *s*.

4.7 Specification of Input Parameters

The following Table 5 lists the available user-input parameters. The **PRC_REACT** parameter is required to be provided by the user to define the grid topology for all of the grid modeling features described here. The following indexes are used in the index domain of the parameters:

Index	Meaning	Index	Meaning
r	Region	c	Commodity (other than grid node)
datayear	Period / Milestone year	s	Timeslice
p	Process	u	Unit type
n	Grid node commodity	cur	Currency

Table 5: **Input parameters for TIMES Grid Features**

Input parameter (Indexes)[1]	Related parameters[2]	Units / Ranges & Default values & Default inter-/extrapolation[3]	Instances[4] (Required / Omit / Special conditions)	Description	Affected equations or variables[5]
COM_CSTBAL (r,datayear,n,s,type, cur)	COM_CSTNET, COM_CSTPRD	• TIMES cost unit • [0, INF); default value: none • Default i/e[6]: standard	• Required for each commodity for which grid balance costs are to be accounted.	Cost on generation, imports, exports, net im-ports, consumption, or net positive generation at node n.	• EQ_OBJBAL
PRC_REACT (r,datayear,p)		• Relative value • [0, INF); default value: none • Default i/e: standard	• Required for each transmission line to be included in the grid system	Reactance of grid transmission line p.	• EQ_GR_POWFLO
GR_GENLEV (r,c)	GR_GENLEV, GR_GENMAP, GR_GENFR	• Value of 1, 2 or 3. • default value: none	• Required for all electricity generation commodities	Characterization of grid connectivity of generation commodity.	• EQ_GENALL • EQ_DEMALL
GR_GENMAP (r,p,u)	See above	• Dimensionless • [0, 1] (usually 1); default value: none	• Required for all generation processes and exogenous imports / exports (if any)	Mapping of generation technologies to generation unit types.	• EQ_GENALL
GR_GENFR (r,datayear,n,u)	See above	• Dimensionless • [0, 1], default value: none • Default i/e: standard	• Automatically normalized	Fraction of generation from unit type u to be allocated to grid node n.	• EQ_GENALL

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[1] The first row contains the parameter name, the second row contains in brackets the index domain over which the parameter is defined.

[2] This column gives references to related input parameters or sets being used in the context of this parameter as well as internal parameters/sets or result parameters being derived from the input parameter.

[3] This column lists the unit of the parameter, the possible range of its numeric value [in square brackets] and the inter-/extrapolation rules that apply.

[4] An indication of circumstances for which the parameter is to be provided or omitted, as well as description of inheritance/aggregation rules applied to parameters having the timeslice (**s**) index.

[5] Equations or variables that are directly affected by the parameter.

[6] Abbreviation i/e = inter-/extrapolation

Input parameter (Indexes)[1]	Related parameters[2]	Units / Ranges & Default values & Default inter-/extrapolation[3]	Instances[4] (Required / Omit / Special conditions)	Description	Affected equations or variables[5]
GR_DEMFR (r,datayear,n,s)	GR_ENDFR GR_GENFR	• Dimensionless • [0, 1]; default value: none • Default i/e: standard	• Only taken into account in region r if GR_ENDFR has not been specified in r • Automatically normalized	Fraction of total demand to be allocated to grid node n in timeslice s.	• EQ_ GR_DEMALL
GR_ENDFR (r,datayear,n,c)	GR_DEMFR GR_GENFR	• Dimensionless • [0, 1]; default value: none • Default i/e: standard	• Automatically normalized	Fraction of sectoral demand c to be allocated to grid node n.	• EQ_GR_DEMALL
GR_XBND (r,t)	IRE_XBND	• Dimensionless • [0, 1]; default value: none • Default i/e: none	• Optional bounding parameter	Line overloading coefficient α defining the maximum power level of imports/exports	• EQ_GR_XBND

5. REFERENCES

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