Chapter 1

Overview

[redacted]

1.3 General organization of the data files

This chapter describes the overall organization and syntax of the data files used by any of the three modules described in the remaining of this book.

Data files include *records* and *comments*, as detailed hereafter.

1.3.1 Records

Each record may span over any number of lines. However, each line must not be more than 130 character long. Each record ends up with a semicolon (;).

Each record includes a certain number (at least one) of *fields*. A field is either a real number (numeric field) or a string of characters (character field).

Two successive fields must be separated by at least one space. Similarly, there must be at least one space between the last field of a record and the semicolon that terminates that record.

Only the first 20 characters of a field are read; the remaining of the string is just ignored, without warning. It is thus highly recommended not to have more than 20 characters in a field.

Numeric fields are written in free format : the usual ways of writing numbers (with or without a dot, with or without an exponent, exponent denoted by `E` or `D`, etc.) are accepted.

Any character field must not include more than some number of characters, specified in the documentation. According to one of the above rules, this number is smaller or equal to 20. If this limit is exceeded, the programs stops with an error message.

Uppercase letters are significant within a character field (i.e. two fields that differ by the uppercase/lowercase spelling are different).

If a character field includes a space or a slash (/), it must be enclosed with quotes ('). In between the two quotes, the leading spaces are significant while the trailing ones are ignored. An empty string of character is denoted by ' '.

The first field of each record is a character field which indicates the type of the record. The use of quotes is never needed for those fields, which never include spaces.

Some records have optional fields, necessarily located at the end of the record.

An element such as a line, a transformer, etc. may be defined several times successively in the data files. In this case, the last record read supersedes the previous ones. A message is given at the time the records are translated into internal variables, indicating that the element is redefined.

Records may be distributed over any number of data files, which will be read sequentially. The order in which the records are placed inside the data files does not matter, except when an element is defined several times, for the above mentioned reasons. This allows to create an "incremental" data file, describing the modifications with respect to a base case defined in a previously loaded data file.

1.3.2 Comments

There are three ways to insert comments in the data files:

1. a line in which the first non blank character is an exclamation mark (!) : the 80 characters that follow this symbol are memorized by the program and reproduced on output files;
2. a line in which the first non blank character is a # : this line is simply ignored by the program;
3. anything written after the semicolon that terminates a record and before the end of the line is also ignored.

Note that a comment need not be terminated by a semicolon since it may not span over several lines. If several lines are needed to write the comment, each of them must start with a ! or a #.

Empty lines are just ignored.

Chapter 2

Modelling and data

2.1 BUS record

Specifies the base voltage, the load and the shunt compensation at one bus.

* type of record : BUS
* NAME (max 8 characters) : name of the bus
* VNOM : base voltage, in kV. VNOM is used to set in per unit the parameters of the lines and transformers incident to the bus
* PLOAD : active power load, en MW
* QLOAD : reactive power load, en Mvar
* BSHUNT : nominal reactive power, in Mvar, of the shunt compensation treated as constant admittance. This if the reactive power produced under a 1 pu voltage. A positive (resp. negative) value corresponds to a capacitor (resp. an inductor)
* QSHUNT : nominal reactive power, in Mvar, of the shunt compensation treated as constant power. A positive (resp. negative) value corresponds to a capacitor (resp. an inductor).

The BUS records are used to define the set of buses involved in the load flow computation. It is thus mandatory to declare all the buses through BUS records. If the program subsequently finds a bus not described by a BUS record, the program stops on error.

2.2 LINE record

Lines and cables are represented by a pi equivalent as shown in Fig. 2.1. Series capacitors are also represented by this scheme with R and C set to zero and X to a negative value.

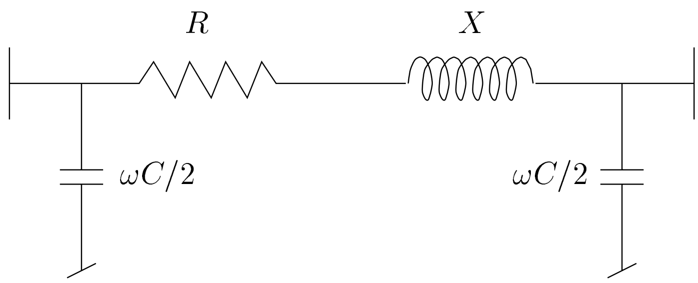

Figure 2.1: line or cable equivalent

The LINE record describes a line, a cable or a series capacitor, modelled as represented in Fig. 2.1.

* type of record : LINE
* NAME (max 20 characters) : name of the line
* FROM_BUS (max 8 characters) : name of the "from" bus (the line orientation is arbitrary)
* TO_BUS (max 8 characters) : name of the "to" bus
* R : resistance R, in Ω
* X : reactance X, in Ω
* WC/2 : half shunt susceptance $\omega C/2$, in μS
* SNOM : nominal apparent power, in MVA. This value should be set to zero if one does not want to specify this power; this will be interpreted as an infinite power.
* BR : on/off status of the line breakers. A zero value indicates that the breakers are open at both ends; any other value means that both breakers are closed.

All lines are memorized, even those which are out of service. A line out of service is not involved in the load flow computation (it appears in the output results with a zero power flow) but it can put back into service in the dynamic simulation.

It is not allowed to have a line connecting two buses with different base voltages (as defined by the VNOM fields of their BUS records).

To have a line connected through a single end, declare the open end as a bus and set the BR parameter to 1.

2.3 SWITCH record

The SWITCH record allows to create a direct connection between two buses.

* type of record : SWITCH
* NAME (max 20 characters) : name of the switch
* FIRST_BUS (max 8 characters) : name of the first bus (the choice is arbitrary)
* SECOND_BUS (max 8 characters) : name of the second bus
* BR : on/off status of the switch. A zero value indicates that the switch is open; any other value means that it is closed.

All switches are memorized, even those which are open. An open switch is not involved in the load flow computation (it appears in the output results with a zero power flow) but it can put back into service in the dynamic simulation.

It is not allowed to have a switch connecting two buses with different base voltages (as defined by the VNOM fields of their BUS records).

2.4 TRANSFO, LTC-V and TRFO records

Transformers are represented by the equivalent shown in Fig. 2.2. B_1 or B_2 can represent the magnetizing reactance. Normally one of these two parameters is zero. n (resp. ϕ) is the magnitude (resp. the phase angle) of the transformer ratio.

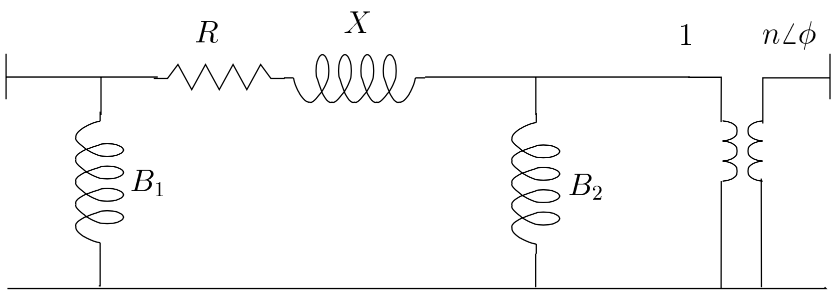

Figure 2.2: transformer equivalent

Three pairs of voltages have to be considered in the modelling of a transformer:

- V_{B1}, V_{B2} : the *base* voltages at the corresponding terminal buses, used to translate the parameters in per unit values

- V_{N1}, V_{N2} : the *nominal* voltages at the corresponding terminal buses
- V_{r1}, V_{r2} : the open-circuit voltages corresponding to the transformer ratio.

ASTRE requires that all parameters are in per unit on the (V_{B1}, V_{B2}) base voltages.

Now, the R, X, B_1, B_2 parameters of Fig. 2.2 are often provided by the manufacturer in per unit on the V_{N1} base voltage. The corresponding per unit values on the V_{B1} base voltage are given by:

$$\begin{aligned} R_{baseV_{B1}} &= R_{baseV_{N1}} (\frac{V_{N1}}{V_{B1}})^2 \\ X_{baseV_{B1}} &= X_{baseV_{N1}} (\frac{V_{N1}}{V_{B1}})^2 \\ B_{1\ baseV_{B1}} &= B_{1\ baseV_{N1}} (\frac{V_{B1}}{V_{N1}})^2 \\ B_{2\ baseV_{B1}} &= B_{2\ baseV_{N1}} (\frac{V_{B1}}{V_{N1}})^2 \end{aligned}$$

The transformer ratio is equal to

$$n = \frac{V_{r2}}{V_{r1}}$$

and on the (V_{B1}, V_{B2}) base voltage it becomes :

$$n = \frac{V_{r2} V_{B1}}{V_{r1} V_{B2}}$$

n may vary in between bounds which are often specified by the manufacturer as corresponding to the nominal voltages $\pm\Delta$ %, namely

$$n^{min}(\%) = \frac{V_{N2}}{V_{N1}}(100 - \Delta) \qquad n^{max}(\%) = \frac{V_{N2}}{V_{N1}}(100 + \Delta)$$

The values to be used in ASTRE are given by :

$$n^{min}(\%) = \frac{V_{N2} V_{B1}}{V_{N1} V_{B2}}(100 - \Delta) \qquad n^{max}(\%) = \frac{V_{N2} V_{B1}}{V_{N1} V_{B2}}(100 + \Delta)$$

Note that the V_{B1}, V_{B2} voltages are not passed on to the program, which assumes that the user expresses the transformer parameters on these base voltages. These voltages must coincide with the base voltages declared at both terminal buses (through the BUS records), which cannot be checked by the program.

The transformer can have a variable ratio, adjusted automatically so as to maintain the voltage in the range $[V^0 - \epsilon, V^0 + \epsilon]$ where V^0 is the setpoint and ϵ half the deadband. The regulated bus can either be the left or the right bus in Fig. 2.2; the ratio varies accordingly. The parameters R, X, B are considered constant when n varies.

In the load flow computation variable transformer ratios are adjusted between the Newton method iterations, as soon as the equations are solved within a specified precision. Each ratio is adjusted proportionally to the voltage error then rounded off to the nearest tap value.

In the dynamic simulation, taps are moved by a single step at a time, while obeying delays between two tap changes (cf section 4.8).

A transformer with fixed ratio should be described by a TRANSFO record. It can also be described by a TRFO record in which some fields are not used.

A transformer with automatically adjusted, in-phase ratio ($\phi = 0$) can be represented either by a combination of TRANSFO and LTC-V records or by a TRFO record.

There must not be two or more LTC-V records relative to the same transformer, otherwise the program stops.

A transformer with complex ratio ($\phi \neq 0$) must be represented by TRANSFO record. If the magnitude of the ratio has to be automatically adjusted, a LTC-V record must be specified.

All transformers are memorized, even those which are out of service. A transformer out of service is not involved in the load flow computation (it appears in the output results with a zero power flow) but it can put back into service in the dynamic simulation.

2.4.1 TRANSFO record

* type of record : TRANSFO
* NAME (max 20 characters) : name of transformer
* FROM_BUS (max 8 characters) : name of the bus on the "1" side of the ideal transformer (cf Fig. 2.2)
* TO_BUS (max 8 characters) : name of the bus on the "n" side of the ideal transformer (cf Fig. 2.2)
* R : resistance R, in % on the (V_{B1}, SNOM) base
* X : reactance X, in % on the (V_{B1}, SNOM) base
* B1 : susceptance B_1, in % on the (V_{B1}, SNOM) base. This is normally a negative value. It can be set to zero
* B2 : susceptance B_2, in % on the (V_{B1}, SNOM) base. This is normally a negative value. It can be set to zero
* N : n, in % on the (V_{B1}, V_{B2}) base

* PHI : ϕ, in degrees
* SNOM : apparent nominal power of the transformer, in MVA. This value must not be zero
* BR : on/off status of the transformer breakers. A zero value indicates that the breakers are open at both ends; any other value means that both breakers are closed.

2.4.2 LTC-V record

* type of record : LTC-V
* NAME (max 20 characters) : name of transformer
* CON_BUS (max 8 characters) : name of the bus whose voltage is controlled by adjusting the transformer ratio n. In the current version of the program, this must be one of the two terminal buses of the transformer
* NMIN : the minimum ratio n^{min}, in %
* NMAX : the maximum ratio n^{max}, in %
* NBPOS : the number of tap positions. Position number 1 corresponds to NMIN, position NBPOS to NMAX. The ratio n can only take a (discrete) value that corresponds to one of these tap positions
* TOLV : tolerance (or half deadband) of the voltage control, in per unit
* VDES : the desired voltage at the controlled bus, in per unit. As long as the controlled voltage differs from VDES by less than TOLV, the tap position remains unchanged
* TEMPIN : delay before the first tap change, in s. This parameter is not used by ARTERE but by QSSS
* TEMPUL : delay in between two subsequent tap changes, in s. This parameter is not used by ARTERE but by QSSS.

2.4.3 TRFO record

In the TRFO record, B_2 is set to zero.

* type of record : TRFO
* NAME (max 20 characters) : name of transformer

* FROM_BUS (max 8 characters) : name of the bus on the "1" side of the ideal transformer (cf Fig. 2.2)

* TO_BUS (max 8 characters) : name of the bus on the "n" side of the ideal transformer (cf Fig. 2.2)

* CON_BUS (max 8 characters) : name of the bus whose voltage is controlled by adjusting the transformer ratio n. In the current version of the program, this must be one of the two terminal buses of the transformer (CON_BUS is either FROM_BUS or TO_BUS). An empty or blank string of characters[1] is used to indicate that the transformer ratio is fixed

* R : resistance R, in % on the (V_{B1}, SNOM) base

* X : reactance X, in % on the (V_{B1}, SNOM) base

* B : susceptance B, in % on the (V_{B1}, SNOM) base. This is normally a negative value. It can be set to zero, if the magnetizing branch of the transformer equivalent is ignored

* N : ratio n, in % on the (V_{B1}, V_{B2}) base

* SNOM : apparent nominal power of the transformer, in MVA. This value must not be zero

* NMIN : the minimum ratio n^{min}, in %

* NMAX : the maximum ratio n^{max}, in %

* NBPOS : the number of tap positions. Position number 1 corresponds to NMIN, position NBPOS to NMAX. The ratio n can only take a (discrete) value that corresponds to one of these tap positions

* TOLV : tolerance (or half deadband) of the voltage control, in per unit

* VDES : the desired voltage at the controlled bus, in per unit. As long as the controlled voltage differs from VDES by less than TOLV, the tap position remains unchanged

* BR : on/off status of the transformer breakers. A zero value indicates that the breakers are open at both ends; any other value means that both breakers are closed.

To have a transformer connected through a single end, declare the open end as a bus and set the BR parameter to 1.

[1] enclosed within quotes !

2.5 GENER record

In ARTERE, generators are merely represented through the so-called PV or PQ buses. Note that there can be only one generator per bus. In the same way, a bus cannot simultaneously have a generator and a static var compensator.

If, initially, the generator is specified as PV, lower and upper limits of reactive generation are monitored. If the limit is violated, the generator bus is converted to the PQ type and the limit is enforced. A generator at its upper (resp. lower) reactive limit reverts to PV type if the voltage becomes greater (resp. smaller) than the imposed voltage. Note that these reactive limits only affect the load flow computation; the dynamic simulation uses distinct models.

A generator can initially be specified PQ in which case there is no testing of limits.

Generators are described by GENER records, as follows.

* type of record : GENER
* NAME (max 10 characters) : name of the generator
* CON_BUS (max 8 characters) : name of the bus to which the generator is connected
* MON_BUS (max 8 characters) : name of the bus whose voltage is controlled by the generator. In the present version of ASTRE, the remote bus voltage control is not available. Hence MON_BUS must be the same as CON_BUS
* P : active power production, in MW
* Q : reactive power production, in Mvar
* VIMP : imposed voltage, in per unit. If VIMP is zero, the generator is treated as a PQ bus with the reactive power production set at the Q value. Otherwise, it is treated as a PV bus and the Q field is ignored
* SNOM : nominal apparent power, in MVA. This parameter must not be zero if one is willing to model the generator in detail (i.e. through a GROUP3 record) in the dynamic simulation
* QMIN : lower reactive power limit, in Mvar
* QMAX : upper reactive power limit, in Mvar
* BR : on/off status of the generator breaker. A zero value indicates that the breaker is open, any other value means that it is closed.

All generators are memorized, even those which are out of service. A generator out of service is not involved in the load flow computation (it appears in the output results with a zero power output) but it can put back into service in the dynamic simulation.

2.6 Static var compensators

2.6.1 Modelling

The block diagram of an SVC is shown in Fig. 2.3. Let j be the *observed* bus (i.e. whose voltage is regulated) and i the *controlled* bus (i.e. where the shunt susceptance varies). i and j can be any of the buses, in particular they can coincide. However, normally, j is a transmission EHV bus and i the bus behind the EHV/MV transformer.

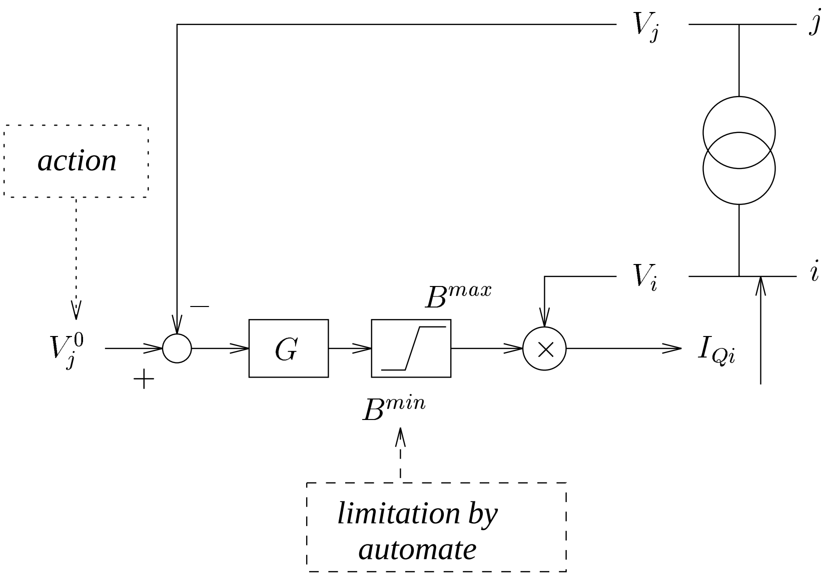

Figure 2.3: static var compensator

We have $I_{Pi} = 0$ while I_{Qi} takes on one of the following forms:

$$
\begin{aligned}
I_{Qi} &= G(V_j^0 - V_j)V_i && (2.1)\\
\text{or} \quad I_{Qi} &= B^{max}V_i && (2.2)\\
\text{or} \quad I_{Qi} &= B^{min}V_i && (2.3)
\end{aligned}
$$

2.6.2 Data: SVC record

* type of record : SVC
* NAME (max 10 characters) : name of the compensator
* CON_BUS (max 8 characters) : name of the controlled bus (where the shunt susceptance shunt varies)
* MON_BUS (max 8 characters) : name of the monitored bus (whose voltage is regulated)

* V0 : voltage setpoint V^0, in pu
* Q0 : reactive power setpoint, in Mvar. Used in the load flow only. If V0 is set to zero, the compensator is treated in the load flow as a PQ bus, with P = 0 and Q = Q0, and no limit is tested. If V0 is nonzero, the Q0 field is ignored
* SNOM : nominal reactive power, in Mvar
* BMAX : maximal nominal reactive power, in Mvar. This is the power produced by the compensator under a 1 per unit voltage, when B is at the maximal value B^{max}
* BMIN : minimal nominal reactive power, in Mvar. This is the power produced by the compensator under a 1 per unit voltage, when B is at the minimal value B^{min}. A negative value if the compensator consumes power, as is usually the case
* G : gain G, in pu on the (V_B, SNOM) base, where V_B is the base voltage at the controlled bus
* BR : on/off status of the compensator breaker. A zero value indicates that the breaker is open, any other value means that it is closed.

2.7 SLACK record

The SLACK records allows to specify which bus is the slack bus. A generator must be connected to this bus.

* type of record : SLACK
* AT_BUS (max 8 characters) : name of the bus of concern

2.8 LFRESV record

A LFRESV record specifies the voltage magnitude and phase angle at a bus. This voltage is either an initial value specified for the load flow computation or the output of the load flow computation, to be used by the QSSS module. In the latter case, the records are generated by the ARTERE module (see section 3.4).

* type of record : LFRESV
* BUS (max 8 characters) : name of the bus of concern
* MODULE : voltage magnitude, in per unit
* PHASE : voltage phase angle, in radian.

2.9 Defining zones and bus participations

The BUSPART record specifies that a bus belongs to a zone; it also allows to specify active and reactive participation factors.

A zone is defined as a set of buses. For a given zone, there are as many BUSPART records as there are buses in the zone. The zone can include any bus, in particular, the branches connecting the buses in a zone need not make up a connected sub-system.

Different zones can overlap, i.e. a bus can simultaneously belong to several zones.

The participation factors are interpreted in a number of manners, depending on the action or the automatic device referring to the zone. We will meet them at several places of this documentation.

* type of record : BUSPART
* ZONE (max 8 characters) : name of zone to which the bus belongs. The zones are created as different zone names are discovered during the reading of BUSPART records
* BUS (max 8 characters) : name of the bus of concern
* PARTP : active power participation factor
* PARTQ : reactive power participation factor.

2.10 Reactive power limits from GROUP3 and OXL records

If the appropriate option has been chosen (see section 3.2), ARTERE computes and monitors and accurate reactive power upper limit, determined from the GROUP3 and OXL records available for the generator of concern. Thus, ARTERE automatically extracts the relevant parameters out of the dynamic data used by QSSS.

Refer to section 4.3 for a detailed description of the GROUP3 record. The fields used by ARTERE are : NAME, XD, XQ, XL, M and N.

Refer to section 4.11 for a detailed description of the OXL record. The fields used by ARTERE are : NAME, EQ1 and EQ2.

The accurate reactive power limit replaces the QMAX value of the GENER record. It is updated each time a modification is applied to the system (loss of a generator, change in load or generation, etc.).

This feature does not apply to generators specified of the PQ type (through a zero VIMP parameter in the GENER record), nor to generators out of service.

If any of the GROUP3 or OXL records is missing, the QMAX value of the GENER record is used.

2.11 Active power participations from GROUP3, GROUP-PV and TURLIM records

If the appropriate option has been chosen (see section 3.2), ARTERE distributes any active power imbalance over a set of generators, according to the participation factors defined in the GROUP3 or GROUP-PV record. It also takes into account turbine active power limits specified in the TURLIM record.

Refer to section 4.3 for a detailed description of the GROUP3 record. The fields used by ARTERE are : NAME and ALPHA.

Refer to section 4.14 for a detailed description of the TURLIM record. The fields used by ARTERE are : NAME, PMIN and PMAX.

If no GROUP3 or GROUP-PV record is specified for the generator of concern, the participation is set to zero. If this holds for all generators (which is equivalent to having the option not activated), the active power imbalances are compensated by the slack-bus (as for the change in active power losses). Refer to section 3 for a description of how active power imbalances are handled.

If a participation is defined but no TURLIM record is available, infinite limits are assumed for the generator.

2.12 Secondary voltage control from RST-PIL and RST-GEN records

If the appropriate option has been chosen (see section 3.2), ARTERE adjusts the generator voltages according to a (simplified) secondary voltage control, as described in section 3.8. ARTERE extracts the relevant parameters from the RST-PIL and RST-GEN records.

Refer to section 4.19 for a detailed description of the RST-PIL record. The fields used by ARTERE are : PIL-BUS, VPCONS and SWITCH.

Refer to section 4.19 for a detailed description of the RST-GEN record. The fields used by ARTERE are : GEN-NAME, PIL-BUS, QNOM, USMIN, USMAX and SWITCH.

3.2 Load flow control parameter file

When launched ARTERE requests a file containing parameters to control the computation. These parameters are listed hereafter.

ARTERE uses Newton method. During the iterations, the following ”mismatches” are computed:

$e_{Pmax} = \max_i |e_{Pi}|$ where e_{Pi} is the error on the i-th active power equation and the maximum is taken over all these equations

$e_{Qmax} = \max_i |e_{Qi}|$ where e_{Qi} is the corresponding error on the i-th reactive power equation

$e_{Smax} = max_i \sqrt{e_{Pi}^2 + e_{Qi}^2}$ is the corresponding apparent power error.

The problem is considered solved once e_{Pmax} and e_{Qmax} are below specified thresholds, all control laws are satisfied and all generators and SVCs are within their reactive limits.

e_{Smax} is used to check that the solution is accurate enough (although not as accurate as specified by the e_{Pmax} and e_{Qmax} thresholds) before performing the following:

1. keeping the Jacobian constant to save some computing time;
2. checking the generator and SVC reactive power limits and enforcing the latter if needed;
3. adjusting the transformers ratios and phase shifts to control voltage magnitudes and active power flows, as specified;
4. adjusting generator voltages according to secondary voltage control (if any).

Finally, the iterations can be stopped as soon as there is an indication of divergence, in order to save computing time, especially when analyzing a large set of contingencies. To this purpose the quadratic index

$$\varphi = \sqrt{\sum_i e_{Pi}^2 + e_{Qi}^2} \tag{3.1}$$

is monitored. Under normal convergence conditions, φ decreases from one iteration to the next. Hence, the algorithm stops at the iteration k such that :

$$\frac{\varphi(k)}{\varphi(k-1)} > 1.1 \tag{3.2}$$

Note that this test is skipped at any iteration k following the switching of generators or SVCs under limit, the adjustment of transformer ratios and phase shifts, or the adjustment of generator voltages according to secondary voltage control. Indeed, these adjustments make φ increase and this increase has nothing to do with divergence.

The following table lists all the parameters to be provided in the file. The data may be written one per line, in free format.

The last column of the table shows the default values assigned by ARTERE. Check the adequacy of these values before using them !

Table 3.1: Control parameters of ARTERE

value of e_{Pmax}, in MW, below which active power flow equations are considered solved	0.1
value of e_{Qmax}, in Mvar, below which reactive power flow equations are considered solved	0.1
maximum number of iterations. If this number is exceeded, the computation stops	20
value of e_{Smax}, in MVA, below which the Jacobian is kept constant	10
value of e_{Smax}, in MVA, below which the transformer ratios and phase shifts are adjusted to control voltage magnitudes and active power flows	10
value of e_{Smax}, in MVA, below which generator and SVC reactive power limits are checked, and enforced if needed	20
value of e_{Smax}, in MVA, below which generator voltages are adjusted according to secondary voltage control (if any), as defined in Section 2.12	10
a y (for yes) or a n (for no) to indicate whether the generator reactive power upper limits should be determined from GROUP3 and OXL records: see section 2.10	y
a y (for yes) or a n (for no) to indicate whether active power imbalances resulting from system modifications or contingencies should be distributed over generators according to data specified in GROUP3, GROUP-PV and TURLIM records: see section 2.11	y
a y (for yes) or a n (for no) to activate the early divergence test based on the function, as explained above	n