6. Synchronous machine dynamics

In the middle of eighties, the present Type 59 synchronous machine model program was implemented and put into practical use in EMTP. In the first half of nineties, also Type 58 model, which has significant improvement from the former, was put into practical use in ATP-EMTP. Most sources of AC power systems are synchronous generators, so the dynamics of the machines are of great interest, especially regarding relatively short time interval of phenomena. Only time domain analysis is applicable to such fast phenomena as down to sub millisecond. In such circumstances EMTP is a significantly useful tool in power system dynamics analyses. As the special feature of Type 58, calculations are stable especially in asymmetrical circuit conditions such as non-transposed over-head lines, which are mostly applied in today's power systems.
It should be noted the present type 59 involves a great bug calculation of saturation in magnetising.
The usage is mostly common by both, excepting write "58" or "59". In this chapter, therefore, mostly Type 58 is explained.

6.1 Machine parameter coding

What are written in the "Role Book", in Chapter Ⅷ "Dynamic Synchronous Machine", are not perfectly updated, so the present updated coding is to be shown in this section.

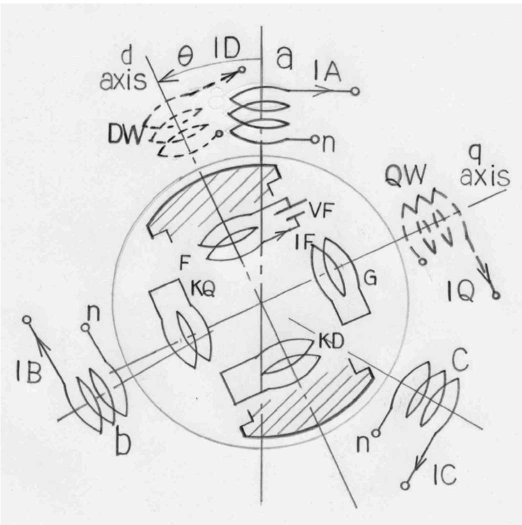


Fig. 6.1 SM modelling in ATP-EMTP
DW and QW are used only in Type 59

The figured modelling in ATP-EMTP synchronous machine is shown in Fig. 6.1 (2P machine). Two coils in each d and q axis model the rotor. As for the stator, in Type 59, three phase coils are replaced by two coils in d and q axes, whereas, in Type 58, three phase coils are applied as they are. The basic equations in Type 58 are as follows.
For each coil voltage,

$$V_j = -R_j i_j - \frac{d}{dt} L_{jk} i_k$$

j,k : a, b, c, F, G, KD, KQ
L_{jk} : time varying functions, depending on the angle between Rotor and Stator

As for torque,

$$T = \sum_j i_j \sum_k i_k \frac{d}{d\theta} L_{jk}$$

These differential equations are numerically calculated.
By inputting machine data shown later, the necessary constants in the equations are calculated, where some assumptions are introduced. Today, the calculations are considered appropriate in obtaining the machine constants.
Typical data coding of Type 58 is shown below. (Others are as written in Role Book, Ⅷ.)

```
=======================================================================
C                  3-PHASE SYNCRONOUSE GENERATOR
C                    1300MVA-19KV-50Hz, 4P
C =====================================================================
C BUS   |VIAMPLITUDE|FREQ.HZ   |ANGLE.DEG|                  |START.SEC|STOP.SEC
C *----||||--------||--------||--------||--------||--------||--------||--------
58VG1A    15513.     50.0        -30.
```

```
58VG1B
58VG1C
PARAMETER FITTING       2.1         {Short-circuited Time Constants applied.
C |G E||NP| SMOUTP || SMOUTQ ||  RMVA  ||  RKV   || AGLINE ||   S1   ||   S2
 1 1  1  4  1.0        1.0       1300.      19.0     -1600.     1980.     3600.
            1.0        1.2       1.0        1.2      -1.  {Same as d-axis
C   RA   ||   XL   ||   XD   ||   XQ   ||  XD'   ||  XQ'   ||  XD''  ||  XQ''
 0.0025     0.18       1.51      1.75      0.42      .55       .30       .28
C  TDO'  ||  TQO'  ||  TDO'' ||  TQO'' ||  XO    ||  RN    ||  XN    || XCAN
 2.52      0.18       .042      .0313     .17      .0191      5.
C   MASS  |(EXTRS) || (HICO) || (DSR)  || (DSM)  || (HSP)  || (DSD)  |
 1          1.0        1.5       0.0       0.0       0.0       500.
BLANK CARD ENDING MACHINE DATA
C OUTPUT REQ. Full Ordering  ------------------------------------------
  11
  21
  31
  51
BLANK
C CONNECTION TO TACS
C 71EX1                          {For TACS Controling Field Exciter
  FINISH
BLANK CARD ENDING SOURCE CARDS
C |----||----||----||-------------||-------------|== CAO LOAD FLOW REQUEST ==
C 1VG1A  VG1B  VG1C          1.17E06  10970.
C BLANK CARD ENDING FIX-SOURCE / CAO LOAD FLOW CARDS
=============================================================================
```

Note:

- In the 2nd and 3rd lines, only 58 and node names are to be written. Voltages, frequencies and angles are automatically introduced as symmetrical three phase AC.
- < 2.0 of PARAMETER FITTING corresponds to open circuit time constants are to be used.
  > 2.1 of PARAMETER FITTING corresponds to short circuit time constants are to be used.
- "1" in col. 7 of 5th line corresponds to metric unit mechanical constants are to be used.
- For R and X, p.u. values (machine rating bases) are to be applied.
- For time constants, "second" is to be used as the unit.
- If XCAN (Caney reactance) can be applied, transient rotor coil currents such as during short-circuiting are more correctly calculated. For armature currents, little influence is introduced. Without introducing the value, XL value is automatically introduced as XCAN.
- To write 11, 21, 31, and 51 in Output ordering cards yields full out put for one mass machine case and generally recommended.
- For initialising Type 58 machine, CAO LOAD FLOW option is applicable, which may introduce better results especially asymmetrical circuit cases. The usage of which is identical to FIX SOURCE, see data files in the following example case.

6.2 Some examples

No-load overhead line charging current supplying

In the first example, no-load overhead line charging current case is taken up. The total system layout is shown in Fig. 6.2 where No. 2 plant and infinitive capacity of source (voltage source) are disconnected. Only No. 1 plant generator is supplying overhead line's capacitive charging current.

The overhead line is modelled in non-transposed double-circuited type, where parameters are calculated in 50 Hz. It should be noted that in calculating machine dynamics, phenomena are mostly in power frequency, so power frequency based line parameters are to be applied. Phase line locations are “a”, “b” and “c” from the top in one side, and “c”, “b” and “a” in the other side for obtaining as better symmetry. Details are shown in Chapter 03 of this text. As for step-up transformers, details are shown

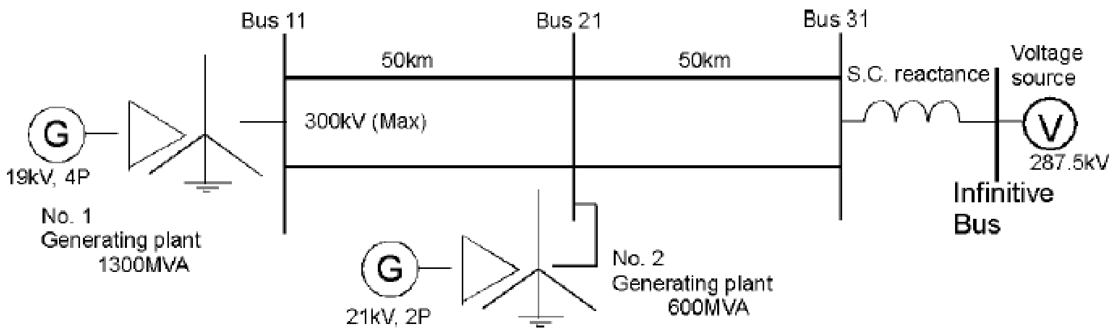
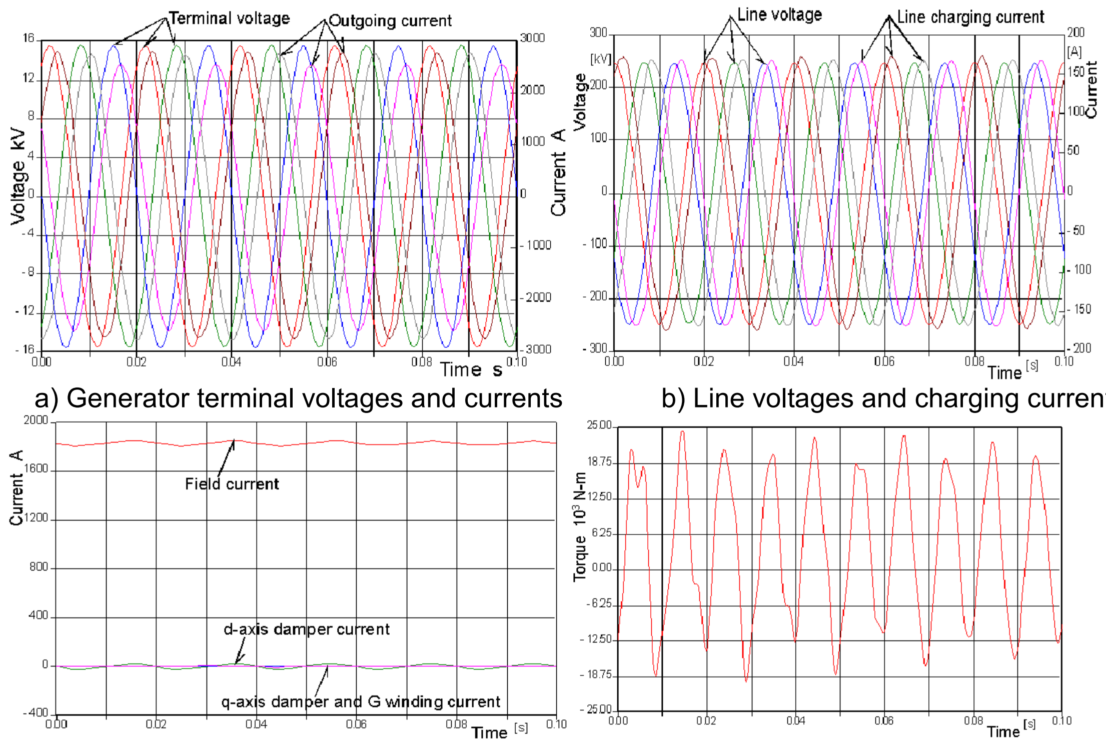


Fig. 6.2 Two machines and infinitive bus system layout

in Chapter 04. For initialisation, by specifying the generator terminal voltages together with phase angles, all variables are to be automatically fixed in this SM program. Then in the case, this procedure was applied. For details of the data coding, see attached data file DATA6-02.DAT.

Note:

- Transformer saturation characteristics may introduce violence in calculation. The main cause seems to be inrush current in the magnetising circuit. SM initialisation and overriding initial condition to non-linear element (Type 93 reactor) is not compatible. In SM transient calculation, as less influence by the saturation is supposed, such non-linear element(s) should be excluded. For introducing transformer magnetising circuit, see Data6-0x.dat, where inrush current still exists.



a) Generator terminal voltages and currents b) Line voltages and charging currents

c) Rotor winding currents d) Air gap torque

Fig. 6.3 No-load transmission line charging by a synchronous generator

- Max allowable step time was approx. 100 μs in the case. By longer step time, diverge may arise. The critical value depends on also the circuit parameters (transmission line, load circuit, etc.).

- Generally, imaging actual systems, numerous times of “Try and error” process is inevitable for optimum calculation even such simple cases.

Some results are shown in Fig. 6.3. The HV line charging voltages and currents are shown in b) and the generator terminal voltages and outgoing currents are in a). In HV side, asymmetry is not significant due to the phase line location crossing. In generator side, on the other hand, some asymmetry exists in the currents. The cause seems to be “Delta-Wye connection” of the step up transformer, i.e., the currents out of Delta connected coils are the subtraction of the coil currents corresponding to the HV side currents. Subtraction often introduces higher asymmetry. The steady state rotor winding currents in symmetrical condition are to be constant, i.e. the rotor and the armature flux rotate in an equal speed. Nevertheless, Fig. 6.3 c) shows some fluctuations in the rated frequency. The cause seems the asymmetry of the load (transmission line) circuit. In the torque (Fig. 6.3 d)), also ripple of doubled frequency exists.

Load flow calculation

In a circuit composed of generators and voltage sources, where all voltage values and phase angles at generator and source terminals have been beforehand correctly obtained together with appropriate load circuit parameters, all variables within all generators are automatically initialised by giving all of such conditions to EMTP calculation data. The previous case is a simple example.

Obtaining such voltage conditions is generally complicated and of tremendously hard work. “FIX SOURCE” has been widely used for such purpose in ATP-EMTP. “CAO LOAD FLOW”, which was developed lately by Mr. CAO and seems to be superior especially in cases with existing some asymmetry in the circuit, is the same usage and is applicable only to Type 58 SM. Therefore in this section, only CAO LOAD FLOW is explained. (Usage is mostly common to FIX SOURCE.)

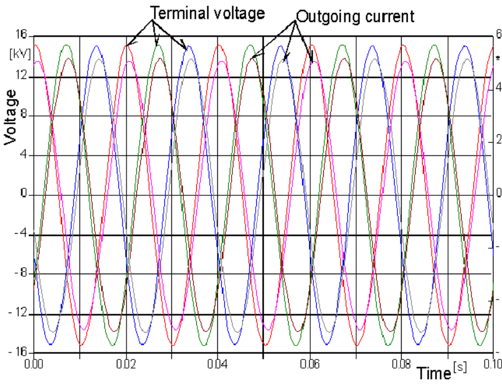
In Fig. 6.2, assuming plant No. 1 (4P machine) to supply full power towards right side infinitive bus and plant No. 2 disconnected, the data file coding is shown in Data6-03.dat attached. In the file the declaration, “CAO LOAD FLOW” is typed before the time card. At the bottom part, the initial load flow condition is typed. In the case, generator terminal voltage and output active power are input, with typing “1” at Column 2. By this procedure, the initial terminal voltage’s phase angle and all machine variables including the reactive power are automatically and appropriately calculated.

By typing “0” instead of “1”, active power and reactive power (generator direction) are to be specified. By “2”, reactive power and phase angle are to be specified. By such procedure, the rest variables are automatically and appropriately initialised.

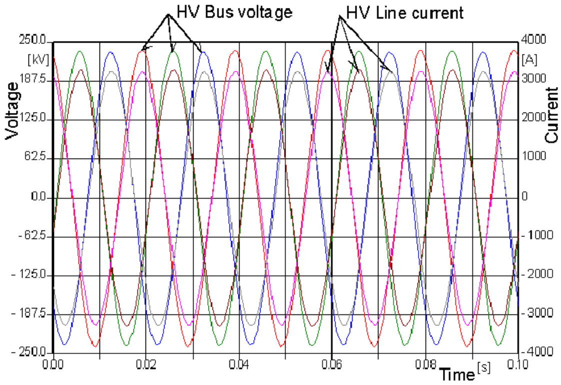
Some results are shown in Fig. 6.4. In a), generator terminal voltage and supplying current are shown. The current value corresponds to 1300MVA X 0.9 of full active power at 19kV. The current is slightly lagging. On the other hand, in Fig. 6.4 b) the transmission line voltage and current are in a same phase angle, i.e. power factor is ca. 1.0. Due to the transformer’s short-circuit reactance, generator side current has some lagging component. The transmission line current value seems to just appropriate. From the generator terminal voltage and current, the generator supplying apparent power is calculated as 1210 MVA, where the active power is specified (in CAO LOAD FLOW) as 1170 MW (= 0.9 X 1300 MVA) in the data.

c) shows detailed voltage phase angle difference along the transmission line. By existence of active power flow, along the line towards downstream, voltage phase angle is delayed.

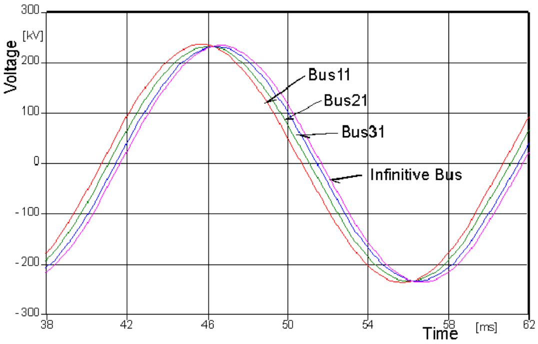
d) shows air gap torque and angle of the d-axis based on the infinitive bus voltage. Both are compared to the case of no-load transmission line charging current supplying case. Values seem to be appropriate, but the cause of the fluctuation in the torque is not clarified yet.



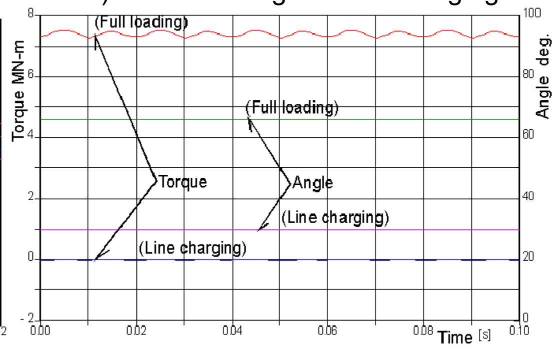
a) Gen. terminal voltages & currents



b) HV bus voltage & Line charging current

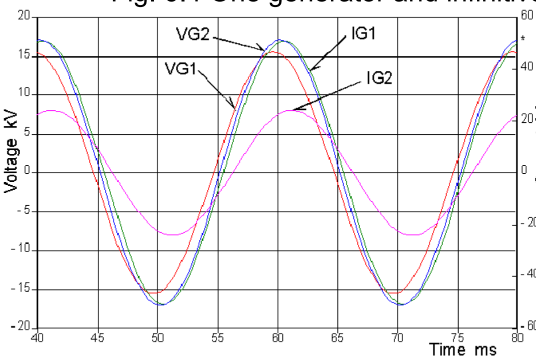


c) Voltages along the line

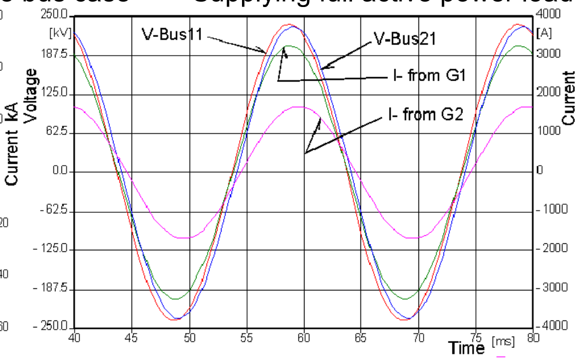


d) Air-gap torque & d-axis angle

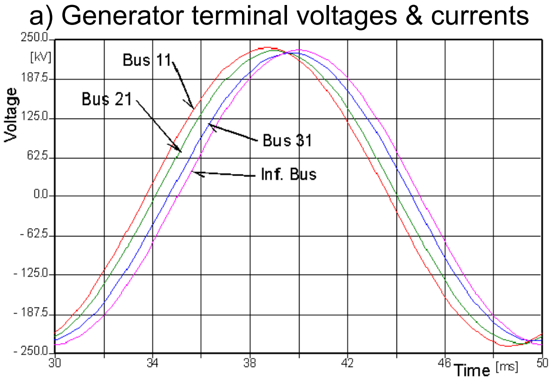
Fig. 6.4 One generator and infinitive bus case ----- Supplying full active power load



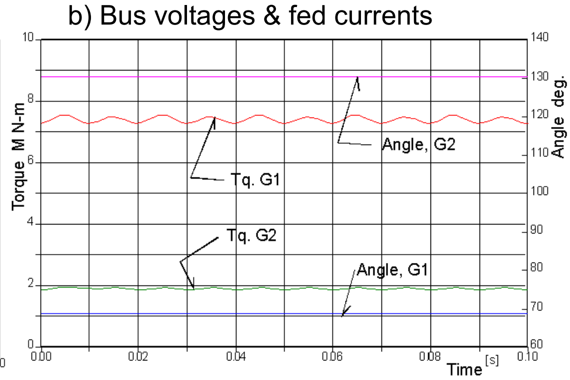
a) Generator terminal voltages & currents



b) Bus voltages & fed currents



c) Voltages along the transmission line



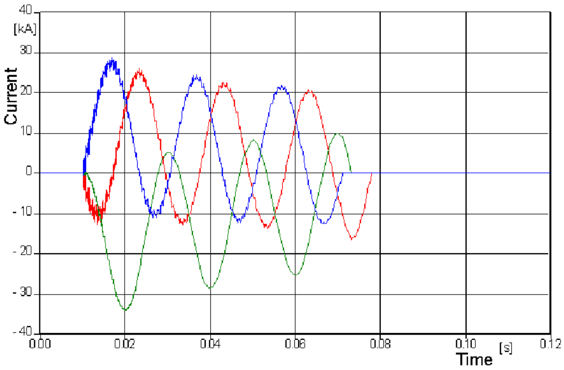
d) Generator torques & d-axis angles

Fig. 6.5 Two generators and infinitive bus case ---- Supplying full active power

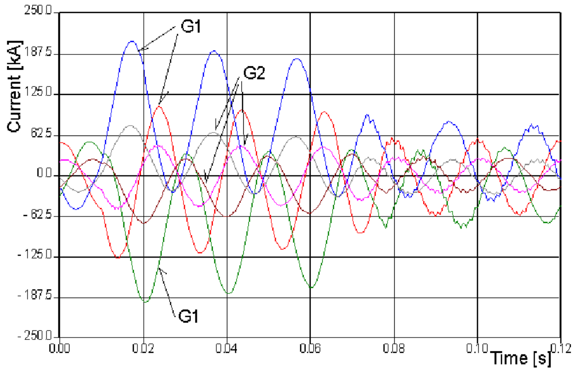
In the next example, two machines are feeding load power. All of components in Fig. 6.2 are connected and both generators are feeding full active powers while the reactive powers are automatically fixed by CAO LOAD FLOW, details are shown in Data6-04.dat. Some results are shown in Fig. 6.5. In a), generator terminal voltages and feeding currents are shown in comparison, G1 terminal voltage phase angle is a little advanced compared to G2, while the current phase angels are respective. G1 and G2 feeding apparent powers are calculated to be 1185MVA and 620MVA respectively.
HV side voltages and currents of the plants are shown in b). The phase angles are advance by 30 degrees compared to the lower voltage side due to Delta – Wye connection, and the wave shape relationships are same in both sides. The voltage phase angle relation along the transmission line is shown in Fig. 6.5 – c). Angle differences in Bus21 – Bus31 – "Inf.-bus" are apparently higher by higher active power transmission, compared to the one generator case in Fig. 6.4 – c). As for the voltage amplitudes, the middle part is the lowest. This will be explained in Appendix 6.3.
d) shows air gap torques and rotor's d-axis angles of two generators. Ripples in both generator torques are not yet thoroughly clarified.

Sudden short-circuit
Next calculation is for sudden short-circuit, i.e. to calculate transients when short circuit occurs. In the first example, assuming three phase simultaneous short circuit near Bus 11 and clearing after several tens milli-seconds. As for details of the data coding, see Data6-05.dat attached. Some results are shown in Fig. 6.6.
Three phase fault current is shown in a). What is notable is the AC component amplitude gradually damps during short circuiting. The cause will be shown in d) and e). The fault current is the sum from G1, G2 and infinitive bus through relevant reactances (transmission lines, etc.).
b) shows the generator side currents during the fault. The maximum ac amplitude of G1 is approximately twice of the rated current which is limited by the generator's sub-transient and transformer reactances.
c) shows bus voltage of before, during and after the faulting. At the instant of the fault clearing, the ac component of the voltage (recovery voltage) shows damping by ca. 15% compared to the pre-faulting value. Directly this corresponds to the damping of armature coil linkage flux. (See e)) This shows (transient) recovery voltage immediately after fault clearing near generator(s) is more or less damped.
d) shows rotor coil currents. During steady state, only the field coil currents flows (steady DC). But during the transient, some value of AC and DC flow with respective damping. These damping are the cause of the damping in short circuit current and recovery voltage.
e) is the d-q plain representation of armature d-q domain coil flux linkages (See Fig. 6.1). In steady state, both coils flux linkages are steady, i.e. the initial point during steady state is upper right position. During faulting via transformer impedance, the flux trace draws smaller circle. If short circuit occurs at the generator terminal, i.e. the voltage equal to zero, the full value of the flux is trapped, then the trace is to be a big circle with a radius of the initial flux value. Details will be explained in the Appendix 6.1. (Flux linkage output is applicable using TACS, see the same Appendix.)
f) shows rotor d-axis position and the rotating velocity change. During faulting, due to mainly reactive power output only, the generator more or less accelerates and this acceleration in the most important cause of transient stability failure. The phenomena is well analysed by EMTP simulation. In the next chapter, details will be shown.

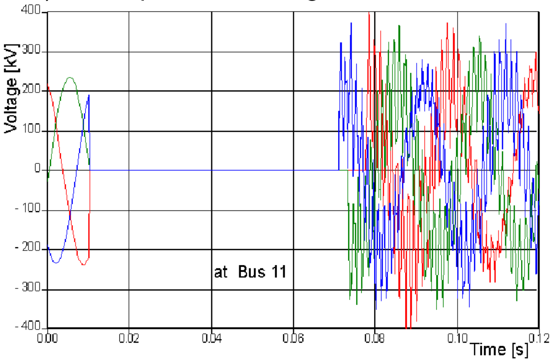
In chapter 05 fault current zero skipping is briefly discussed. Also in this chapter, the subject is to be surveyed introducing a few kinds of faulting condition.



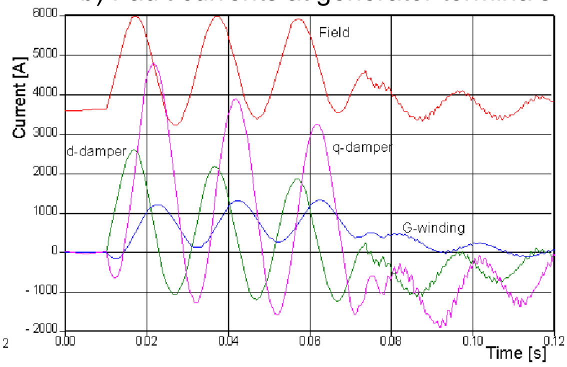
a) Three phase earthing fault currents



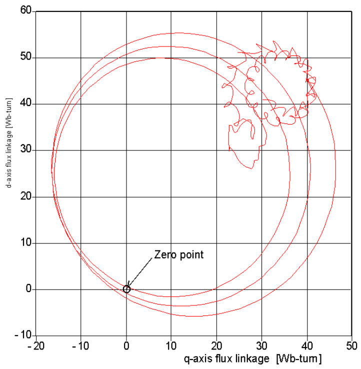
b) Fault currents at generator terminals



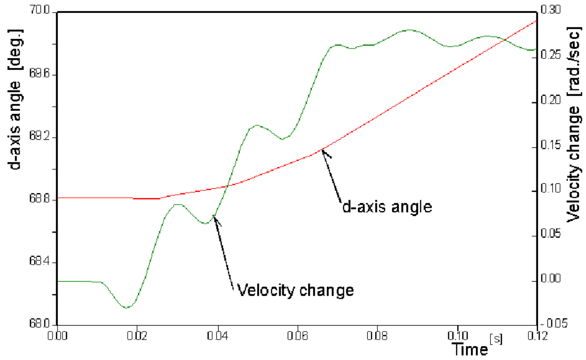
c) Bus voltages at the fault point



d) G1 rotor coil's currents

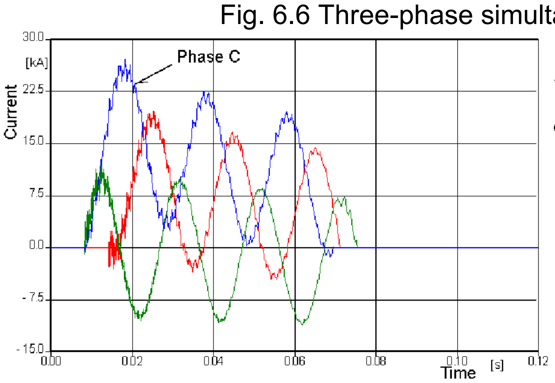


e) Armature current in d-q domain

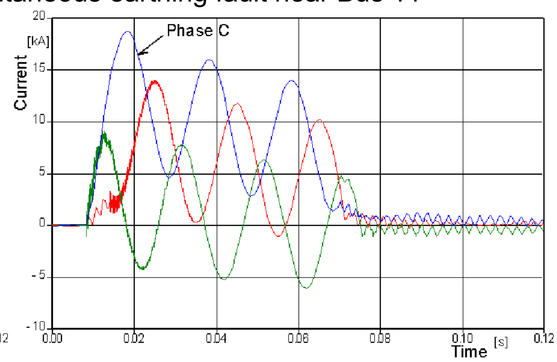


f) G1 d-axis angle and Velocity change

Fig. 6.6 Three-phase simultaneous earthing fault near Bus 11

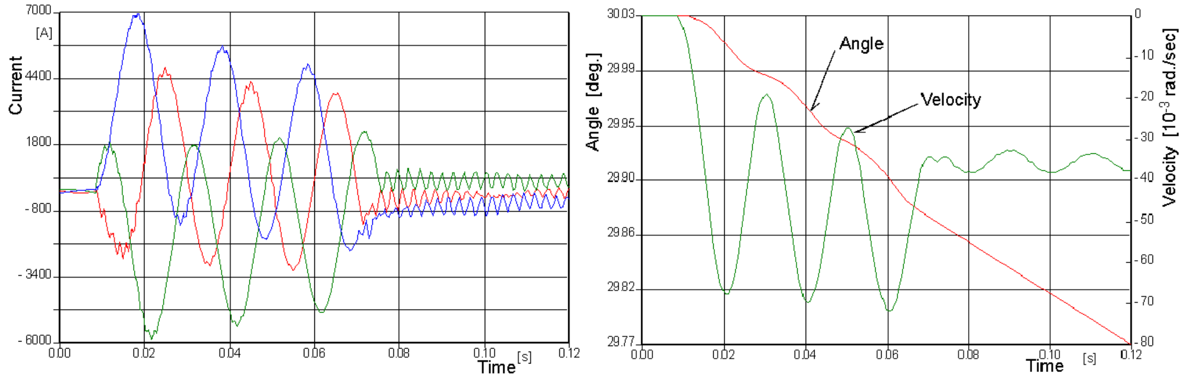


a) Total fault current



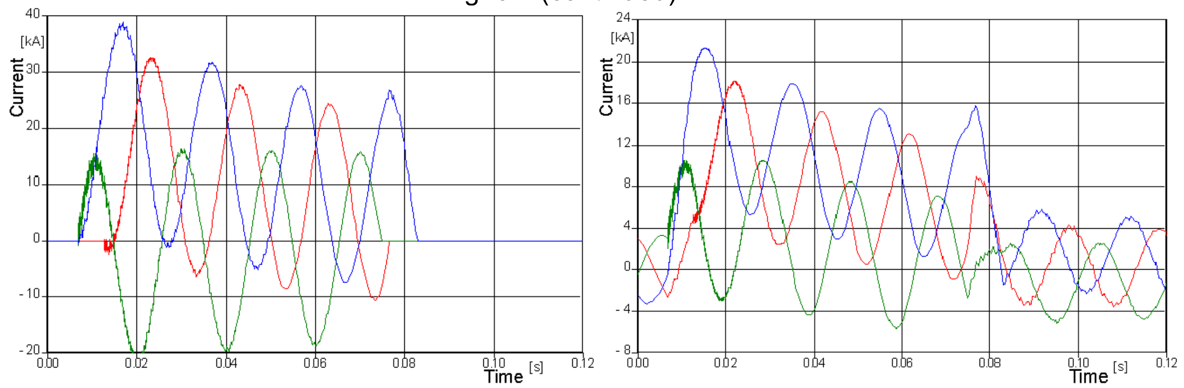
b) Fault current from No. 1 plant

Fig. 6.7 Three-phase non-simultaneous earthing fault under no-load (continuing)



c) Fault current from No. 2 plant d) d-axis angle & velocity change in G1

Fig. 6.7 (continued)



a) Total fault current b) Fault current from No. 1 plant (G1)

Fig. 6.8 Three phase non-simultaneous earthing fault under full loading condition

The first example is shown in Fig. 6.7, where in order to introduce significant zero skipping fault current, three phase non-simultaneous point on wave faulting timing is introduced. The beforehand load flow was of practically no-load. The faulting timing was obtained by “try and error” process.

In a), the total fault current, i.e. the sum of from G1, G2 and the remote infinitive bus, is shown. Though in phase C zero skipping appears for approx. two periods, after several tens milli-seconds from the fault initiation, zero skipping disappears. Then the total fault current can be safely interrupted by a general alternating current circuit-breaker. Nevertheless, current from No. 1 plant shown in Fig. 6.7 b), has very significant zero skipping due to, mostly probably, predominance of damped ac component in the generator circuit and low DC component damping in the circuit. While as for the current from No. 2 plant, shown in c), due to by not only generator circuit but also by transmission line, the parameters of which are linear and relatively low L/R value (DC decrement time constant), the current shows no zero-skipping. What is notable in the case is, as shown in Fig. 6.7 d), the generator is decelerated during the faulting, whereas in the former case, as shown in Fig. 6.6 f) the generator is accelerated. The details will also be written in the next chapter.

Another example is shown in Fig. 6.8, where non-simultaneous three phase fault under full loading condition is applied. The fault initiation timing is the result of numerous times of Try & Error process. In the case only the current from G1 side has significant zero skipping, which may be difficult to be interrupted by a general AC circuit-breaker. Currents from G2 and/or from remote infinitive bus, not shown, has no significant zero skipping due to the circuit composed of transmission line which is of linear parameters and of relatively low L/R value, etc. Then the total fault current, shown in a) has not zero skipping.

From the survey in this chapter as for zero-skipping of fault current, the following are clarified. :

- Zero skipping appears only near generator(s).
- By only quite special point on wave fault initiation timing, it appears.
- Most significant zero skipping appears by three phase fault.

Attached data files :

Data6-00.dat	1300MVA, 4P, 19kV generator and step up transformer parameters
Data6-01.dat	300kV, 410mm**2 X2, 50km Line Constants parameter calculation data
Data6-02.dat	Generator supplying transmission line charging current, 300kV, 100km, 2cct.
Data6-03.dat	One gen. plus Inf. bus case, load flow calculation, CAO LOAD FLOW option applied.
Data6-04.dat	Two gen. plus Inf. bus case, full load flow calculation by CAO LOAD FLOW
Data6-05.dat	Three phase earthing fault near No. 1 plant step up transformer HV side under ditto system condition, three phase simultaneous faulting.
Data6-06.dat	Ditto, but no-load condition and non-simultaneous three phase faulting.
Data6-07.dat	Similar to 6-05 case, but non-simultaneous three phase faulting to create maximum zero skipping fault current.
Data6-0x.dat	Step up transformers with magnetising linear reactances are applied.
Data6-11.dat	Perfect round rotor SM without damper coil, 3.3kV, 1MVA, 2P, 3-phase simultaneous sudden short circuiting under no-load condition. (Asymmetrical short circuit current, i.e. with high DC componet)
Data6-12.dat	Ditto, but point on wave short circuiting to create short circuit current without DC component (Symmetrical short circuit current)
Data6-13.dat	Like data case 6-11, but under full loading condition
Data6-14.dat	Like data case 6-11, but salient pole machine under no load condition
Data6-1F.dat	SM with damper coils both in d- and q- axes. 3 phase simultaneous short circuiting under full load condition.
Data6-20.dat	Basic data of Synchronous machine starting as Induction machine, operated under power frequency.
Data6-21.dat	Checking operation in very low frequency and very low induced voltage, where 1% of values could be applied.
Data6-22.dat	Starting as Induction machine, with 2% of the initial velocity and 1% of the initial voltage, the field current is ca. 50% of the rating.
Data6-31.dat	Simplified representation of voltages along a transmission line, applying L-C ladder circuit. Minimum voltage appears at the middle point of the line.

Appendix 6.1 Synchronous machine sudden short circuit --- description on d-q co-ordinate plane

In Type 59 synchronous machine program, calculation is made as d-q-0 domain variables. Though some demerits exist in Type 59 compared to Type 58, phenomena within the machine are well represented by Type 59. In this appendix, such inside phenomena in sudden short circuit will be discussed for better understanding of synchronous machine dynamics. Therefore, Type 59 is better to be applied.

As for d-q-0 domain calculation method, we can find some materials/literatures easily, so little is necessary to explain. In the first example, we take up the following perfectly symmetrical (non-salient) rotor machine. The machine parameters are, :

Ratings: 3.3kV, 1MVA, 2P, 50Hz

Main constants: $X_d = X_q = 1.5$pu, $X_d' = X_q' = 0.2$pu, $T_d' = T_q' = 0.3$sec.

The machine has no damper coil and is of winded rotor induction motor type one, and some of such ones are applied as variable speed generators. Again, going back to Fig. 6.1, assuming three phase armature coils are suddenly and simultaneously short-circuited. The flux linkage in the armature is trapped at the initial value with damping concerned. Fig. 6A.1 a) shows three phase armature currents during short circuit. In two phases, high value of DC component exists. b) shows armature flux linkage in d-q domain plane, based on the rotor position. As the flux is fixed on the armature, its rotes in d-q plane, drawing a spiral. c) shows rotor flux which is also trapped with damping due to short circuit of the coils (voltage source of field is of zero impedance.).

Assuming two coils, coupled each other, the next equations are easily obtained.

$$\phi_1 = L_1 i_1 + M i_2 \qquad \phi_2 = L_2 i_2 + M i_1$$

Winding turn ratio is assumed to 1.0,

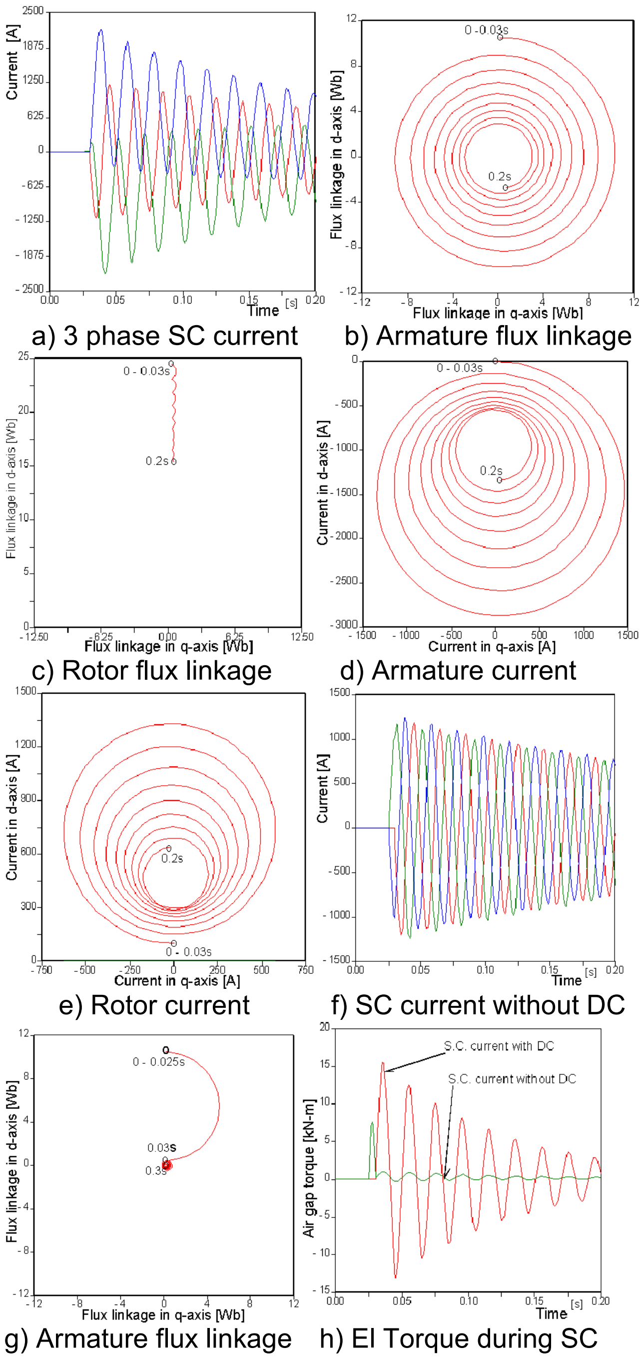
$$L_1 = L_2 = L, \qquad M = kL$$

then we have,

$$i_1 = (\phi_1 - k\phi_2)/L(1-k^2)$$

$$i_2 = (\phi_2 - k\phi_1)/L(1-k^2)$$

As generally k is in the order of 0.9 ---0.95, so as the general understanding, the current is approximately proportional to the flux difference of the two coils. d) and e) show such general trend in relation to b) and c).

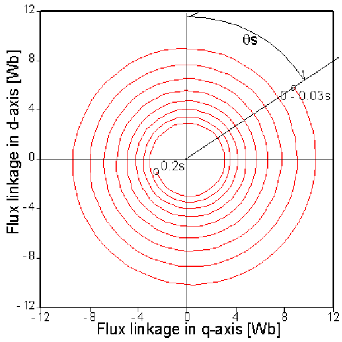


a) 3 phase SC current b) Armature flux linkage
c) Rotor flux linkage d) Armature current
e) Rotor current f) SC current without DC
g) Armature flux linkage h) El Torque during SC

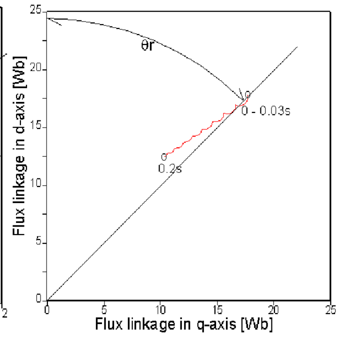
Fig. 6A.1 Sudden short circuit (continuing)

f) shows three phase short circuit currents without DC component. Such currents are obtained by short circuiting between phase b and c at the crest of $V_{b\text{-}c}$, and 90 degree later short circuiting three phases. Armature flux linkage is shown in g), where, excepting 90 degree of the transient time, the value is almost zero. By the flux movement shown in n), this is easily understood.
The great contrast is in the torque shown in h) in comparison with the previous three phase simultaneous short circuiting case. In the previous case, due to the existence of fluxes in both of stator and rotor, high amplitude torque swing appears. In the latter case, due to least flux in the stator, the torque is almost zero. The phenomena may introduce great effect to transient stability, especially during pumping stage. Details will be described in the next chapter as for "back swing."

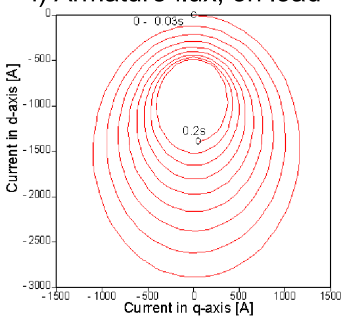
Short circuiting under full loading case is shown in I) and j). By the initial load current, the initial flux position rotates. The difference of the initial angles, $(\phi_S - \phi_R)$ corresponds to the initial load torque.
By salient pole machine, flux changes are almost the same as round rotor machine. Significant difference is in currents. By equations before shown in the previous page, currents are dominated by also inductance(s). In salient pole machine, the inductance values in d- and q- axes are different, therefore the current trace in d-q domain plane is of oval shaped as in k). The result means doubled frequency of DC component fluctuation exists. The fact that short circuit current in salient pole machine has 2nd stage harmonics component is well known.



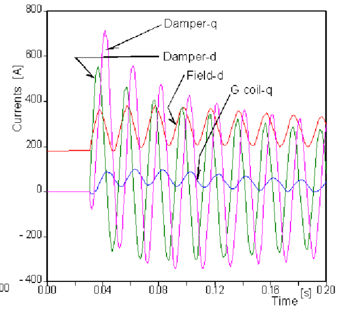
i) Armature flux, on load



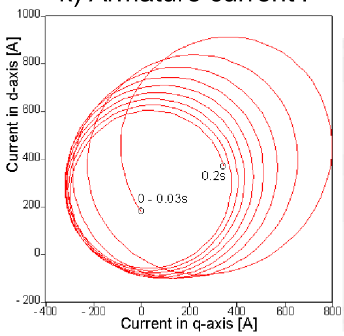
j) Rotor flux, on load



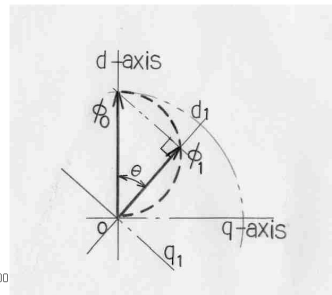
k) Armature current I



l) Rotor 4 coil currents



m) Combined current



n) Flux movement

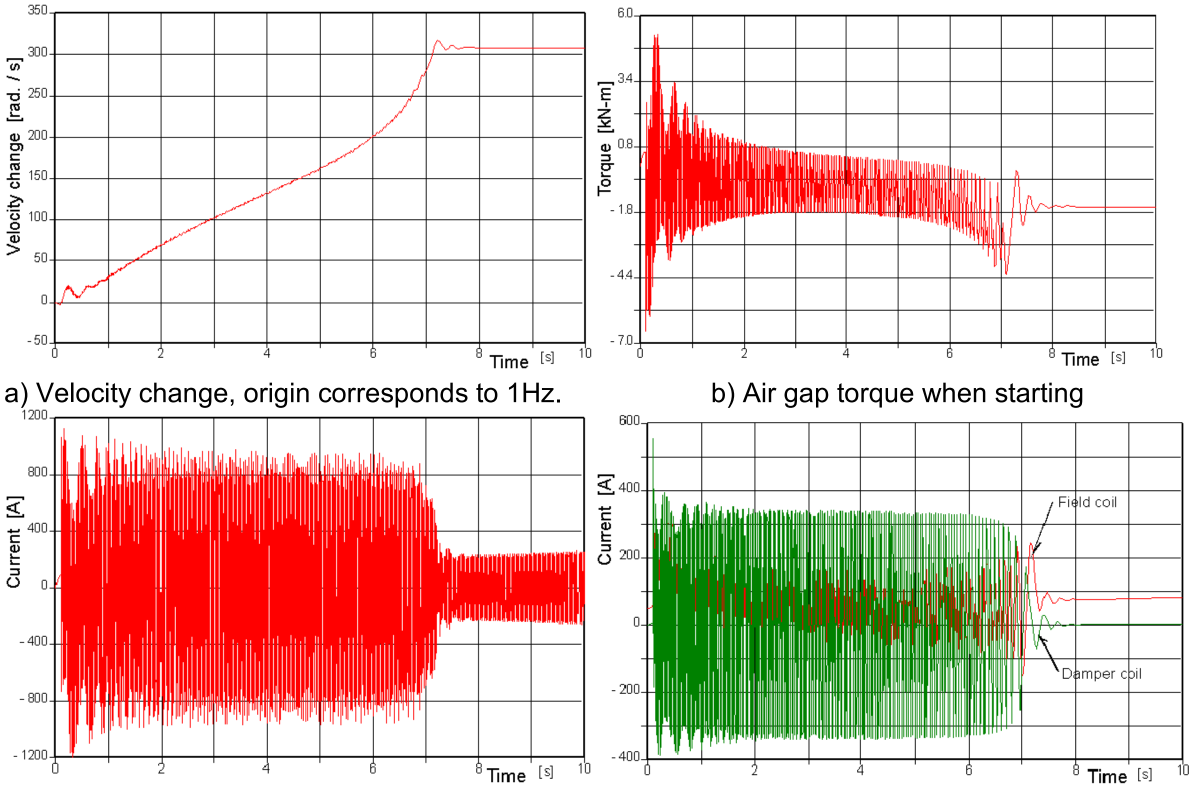
Fig. 6A.1 (continued)

I) shows rotor coil currents of a machine with dampers both in d- and q- axes. Each shows complicated variation in the time domain graph. m) shows d-q plane current trace, each d/q axis component of which is the sum of each two coil currents. Fortunately in EMTP, all of the rotor coils are modeled in a uniform turn number. So, sum of currents is proportional to sum of magnetically motive forces (Ampere – turn). By observing in respect of the total magnetically motive forces in both axes of the rotor, the phenomena shows the quite the same appearance.

Note
For drawing X-Y plot graphs applied in this Appendix, PlotXY.exe is best applicable. Also GTPPLOT.exe is applicable for the purpose.

Appendix 6.2 Synchronous machine starting as Induction motor

Synchronous generators/motors are occasionally started as induction motors, where the field coils are short-circuited. The principle is identical to induction machine. Type 58/59 synchronous machine program in ATP-EMTP was originally developed as in service in near power frequency range. Therefore, for calculating quasi zero speed of phenomena, special care is to be taken.



a) Velocity change, origin corresponds to 1Hz. b) Air gap torque when starting

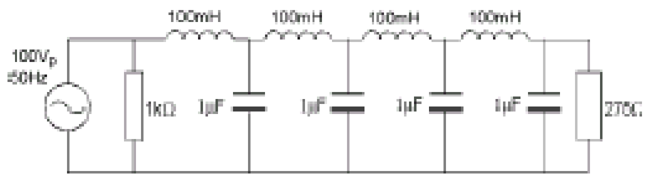
c) Armature current d) Field & Damper(-d) coil currents

Fig. 6A.2 Synchronous machine starting as Induction machine

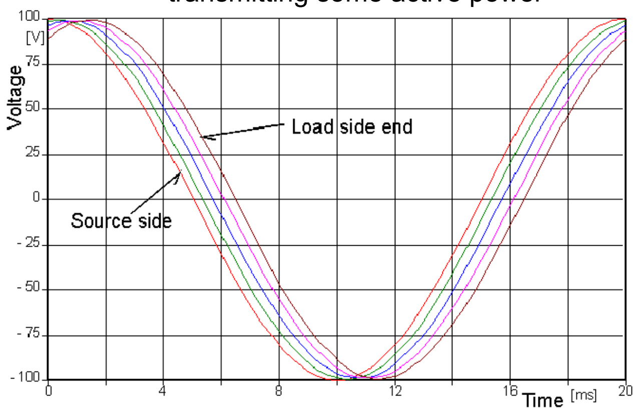
One example is shown in this Appendix, where the followings were applied. :

- Firstly one synchronous machine is taken up, by which steady state operation under power frequency is checked. (See attached Data6-20.dat) The machine ratings here applied are: 3.3kV, 1MVA, 2P, with damper.
- By the machine, operation under very low frequency and very low induced voltage is to be established. (See attached Data6-21.dat) The actually possible minimum was, as in the data, 1% both in frequency and voltage. Care should be taken that the rated voltage and capacity written in the data are to be also 1% of the original ones. Saturation could not be introduced. The cause has not been clarified.
- Then connecting to power frequency AC source, the machine starts as an induction machine. In the case, 2% of the initial velocity was the lowest possible limit. The inducing voltage could be 1% of the rating. (See attached Data6-22.dat) In the case, AC voltage source of zero voltage had been connected initially via the impedance and the voltage value was enhanced afterwards. This method produced stable result. (Some alternatives may be applicable.) In the case, the machine field has been energised by 50% of the rating from the initial, therefore, finally the machine perfectly synchronised to the AC source, without any slip. Care should be taken, in Fig. 6A.2 a), the vertical co-ordinate shows the velocity change and not the absolute value, according to the EMTP program. The initial absolute value is 6.28 rad./s.

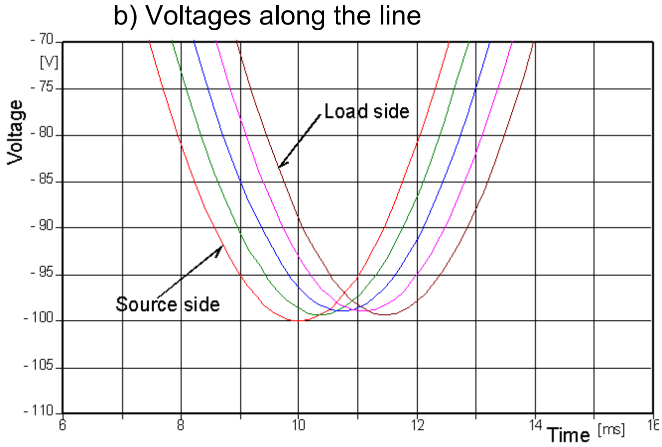
Appendix 6.3 Voltage distribution on transmission line



a) Simplified transmission line modelling transmitting some active power



b) Voltages along the line



c) Voltage enlargement

Fig. 6A.3 Voltages along a transmission line in simplified modelling

In Fig. 6.5 c), the voltage distribution along the transmission line shows minimum at the middle part. This can be represented by the following simple circuit layout.

In Fig. 6A.3 a), a transmission line is represented in most simplified modelling, i.e. multi-stage L-C pie representation. The left end is connected to an AC source and the opposite load resistor. The line is transmitting some active load current.

b) shows voltage distribution along the line, where, as more load side, the phase angles are more delayed.

c) shows the crest part of the voltage in much enlargement. As shown in the figure, minimum voltage exists at the middle point along the line.

By higher active load current, minimum voltage appears at the right side end, and by very light or no load current, right side voltage is highest. Therefore such voltage distribution as in the case, i.e. minimum at the middle point, appears only in very critical circuit conditions.