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On the Testing of Three-phase Equipment Under Voltage Sags

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Abstract—This paper provides insight into the testing of three-phase equipment exposed to voltage sags caused by faults. The voltage sag recovery at the fault-current zeros, leading to a discrete voltage recovery, i.e., the fault is cleared in different steps. In the literature the most widespread classification divides discrete sags into fourteen types. Our study shows that it is generally sufficient to consider only five sag types for three-phase equipment, here called time-invariant equipment. As the remaining nine sag types cause identical equipment behavior in Park or Ku variables, the number of laboratory tests (or of simulations) on equipment under sags is reduced by a ratio of 14/5. The study is validated by simulation of a three-phase induction generator and a three-phase inverter, which are time-invariant, and a three-phase diode bridge rectifier, which is not time-invariant.

Index Terms—Fault clearing, power quality, symmetrical voltage sag, unsymmetrical voltage sag.

I. INTRODUCTION

THE voltage in sags caused by faults has a discrete recovery. Sags are commonly classified into fourteen types [1]. This paper shows that it is generally sufficient to consider only five discrete sag types for grid-connected equipment (e.g., induction and synchronous machines, power inverters or active rectifiers), called time-invariant (TI) in this paper. TI equipment meets the following three conditions: (I) the pre-fault dynamic three-phase electrical variables (e.g., the three-phase currents and/or fluxes) are constant when expressed in Park or Ku variables in the synchronous reference frame; (II) in controlled equipment, the control strategy is implemented in Park or Ku variables (not in abc phase variables); (III) there is no neutral connection.

The remaining nine sag types lead to identical equipment behavior in transformed variables (regardless of the reference frame). Thus, the number of experimental tests (or of simulations) on TI equipment under sags is reduced by a ratio of 14/5.

In order to validate the study, a squirrel-cage induction generator, an inverter and a diode bridge rectifier are simulated during voltage sag events. As the diode bridge rectifier does not meet condition I, the grouping of sags is only applicable to the first two devices. The results illustrate that the grouped sags produce identical effects on both.

II. VOLTAGE SAG CHARACTERIZATION AND CLASSIFICATION

A voltage sag is characterized by four parameters [1], namely duration (\(\Delta t\)), depth (\(\Delta v\)), fault current angle (\(\psi\)) and sag type. Sags are mainly caused by faults. Three-phase faults generate symmetrical sags, i.e., type A sags, while one- or two-phase faults generate unsymmetrical sags, i.e., types B, C, D, E, F and G sags. This classification is given in [2] and Appendix I.

Faults are cleared at the fault-current zeros; that is, fault-clearing does not occur instantaneously but in different steps, resulting in a discrete voltage recovery. The ways to fully clear the same type of fault are classified into fourteen groups in [1], five of which refer to symmetrical sags (named A\(_1\), A\(_2\), A\(_3\), A\(_4\) and A\(_5\)) while the other nine refer to unsymmetrical sags (denoted as B, C, D, E\(_1\), E\(_2\), F\(_1\), F\(_2\), G\(_1\) and G\(_2\)). Appendix II shows the discrete fault-clearing instants for each sag type and the sag sequence during fault clearance.

The sag classification is simplified if the zero-sequence voltage is removed. Then,
- According to Appendix I, sag type B is a particular case of sag type D (a sag type D with \(h = 1/3…1\) has the same positive- and negative-sequence voltages as a sag type B with \(h = 0…1\)).
- According to Appendix I, sag types E and G are equivalent as they have identical positive- and negative-sequence voltages.
- According to Appendix II, sag types A\(_3\) and A\(_5\) are equivalent if the sag sequence during voltage recovery is considered.

Thus, only ten sag types must be studied assuming no zero-sequence voltage: A\(_1\), A\(_2\), A\(_4\), A\(_5\), C, D, F\(_1\), F\(_2\), G\(_1\) and G\(_2\).

III. SAG COMPARISON

The study of sag effects on grid-connected equipment relies on two approaches: to consider or ignore the transformer connections.

A. Considering the Transformer Connections

Let us suppose that a 1-phase-to-ground fault, i.e., a type B
sag, occurs in the power system of Table I. This sag propagates through the different voltage levels, and its profile in abc phase variables is altered by the transformers, as illustrated in that table.

The delta-wye (Dy) and wye-delta (Yd) transformers eliminate the zero-sequence voltage and only modify the phase of the positive- and negative-sequence voltages (they do not alter their modulus if the transformation ratio is unity). Thus, the Dy and Yd transformers change the sag type. In the example of Table I, the type B sag is transformed into a type C sag by the first Dy transformer and then into a type D sag by the second Dy transformer. Regarding Dd or Yy transformers, they are equivalent to two cascade Dy transformers.

With regard to the sag initiation and clearance instants, \( t_i \) and \( t_f \), respectively, the following comments can be made:

- Instant \( t_i \) can take any value as the fault can be initiated at any arbitrary instant.
- Instant \( t_f \) is defined by the fault clearance process and depends on the faulted phases (type of fault) and the fault current angle, \( \psi \). Thus, this instant is not arbitrary, but can take the discrete values in Appendix II only.

Table I also shows the modulus and angle of the transformed voltage in the complex plane, \( v_f \), when applying the Ku transformation \([3]\) (\( v_f \) is a complex notation for the Park dq components) in the synchronous reference frame. This voltage is calculated as

\[
v_f = \frac{1}{\sqrt{2}}(v_a + jv_b) = e^{j(\omega t + \Psi_0)}(v_a + av_b + a^2v_c),
\]

where \( \omega \) is the grid voltage pulsation and \( \Psi_0 \) is the transformation angle at instant \( t = 0 \) s (the transformation angle in the synchronous reference frame is \( \Psi = \omega t + \Psi_0 \)).

It is worth noting that the Ku variables in the synchronous reference frame are used in most equations and examples in the paper only for simplicity reasons, neither the use of Park or Ku variables nor the reference frame affects the results.

As can be seen in (1), the transformed voltage \( v_f \) depends on \( \Psi_0 \), which can be freely chosen. Table I shows that this angle does not influence the time evolution of the modulus of \( v_f \) but alters the time evolution of the angle of \( v_f \) in one offset angle. We will come back to this point in Subsection IV-A.

The results of Table I exhibit the following features:

(a) During the fault, the angle of the phase a voltage, \( \alpha_a \), which depends on the transformer clock number and fault type, varies with the voltage levels (for example, \( \alpha_a = 0^\circ \) at voltage levels I and III in Table I while \( \alpha_a = -90^\circ \) at voltage level II).

(b) As evident, the during-fault voltages (the abc phase and transformed voltages) start and end at the same instants \( t_i \) and \( t_f \) at all levels.

(c) The time evolution of the modulus of \( v_f \) is identical at all voltage levels.

(d) The time evolution of the angle of \( v_f \) is identical at all voltage levels by appropriate selection of \( \Psi_0 \) (e.g., \( \Psi_0 = 0^\circ \) for level I, \( \Psi_0 = -90^\circ \) for level II and \( \Psi_0 = 0^\circ \) for level III).

B. Ignoring the Transformer Connections

In the technical literature sag types are usually modeled without considering the transformer connections (e.g., the sags in Appendix I). It is further assumed that phasors b and c are symmetrical with respect to phasor a, and \( \alpha_a \) is null. Table II repeats the sag types of Table I but modeled by ignoring the transformer connections: the type C sag is shifted by 90°, while the type B and D sags are maintained as in Table I.
The initial and final instants, \( t_i \) and \( t_f \), are time-shifted 90° with respect to those of types B and D.

The time evolution of the modulus and angle of \( v_f \) is time-shifted 90° with respect to that of types B and D.

### C. Final Remarks

The aim of the paper is to demonstrate that several pairs of sag types (e.g., C and D) produce identical TI equipment behavior. Just like the transformed voltages of types C and D only differ in one offset angle in Table I (unless \( \Psi_0 \) is chosen properly), and one time shift in Table II, considering or ignoring the transformer connections is related to the influence of one offset angle (or the \( \Psi_0 \) choice) and of one time shift, respectively, on equipment behavior.

### IV. Transformed Voltage Analytical Expression

The expression for the transformed voltage of an unsymmetrical sag in the synchronous reference frame is obtained from (1) as

\[
v_f(t) = \sqrt{\frac{3}{2}} \left[ V_p e^{-j(2\omega t + \phi_p)} + V_n e^{-j(2\omega t + \phi_n)} \right] e^{j(\phi_p - \phi_n)} ,
\]

where \( V_p \) and \( V_n \) are the rms value of the positive- and negative-sequence voltages, and \( \phi_p \) and \( \phi_n \) are their angles. The modulus and angle of the transformed voltage (2) are

\[
|v_f(t)| = \sqrt{\frac{3}{2}(V_p^2 + V_n^2 + 2V_p V_n \cos(2\omega t + \phi_p + \phi_n))} ,
\]

\[
\alpha_f(t) = (\phi_p - \Psi_0) + \arctan\left( \frac{-V_n \sin(2\omega t + \phi_p + \phi_n)}{V_p + V_n \cos(2\omega t + \phi_p + \phi_n)} \right).
\]

Note that (3) is valid for any unsymmetrical system. As phases b and c are symmetrical with respect to phase a in the sags of Appendix I, angles \( \phi_p \) and \( \phi_n \) are

\[
\phi_p = \alpha_a , \quad \phi_n = \alpha_a + \xi 180^\circ ,
\]

where \( \xi \) is a binary variable equal to 0 or 1 depending on the sag type: \( \xi = 0 \) for sag types A, C, E and G, and \( \xi = 1 \) for sag types B, D and F.

Two observations can be made from (3), which agree with the results of Table I and Table II:

1) The transformed during-fault voltage oscillates at a pulsation equal to twice the grid pulsation (2\( \omega \)).

2) The transformed pre- and post-fault voltage is

\[
v_{PRE-FAULT} = \sqrt{\frac{3}{2}} V e^{j(\alpha_a - \Psi_0)} ,
\]

where \( V = V e^{j\alpha_a} \) is the phasor of the phase a pre-fault voltage. This transformed pre-fault voltage can be chosen as the angle reference for \( \Psi_0 = \alpha_a \). For example, the transformed voltage at level II in Table I is the angle reference for \( \Psi_0 = \alpha_a = -90^\circ \).

### A. Influence of the Initial Angle of the Transformation (\( \Psi_0 \))

Fig. 1a illustrates the \( \Psi_0 \) influence on the transformation of the abc phase voltages of a type D sag with depth \( h = 0.4 \), duration \( \Delta t = 2.5T \) and angle \( \alpha_a = 0^\circ \). It is observed that \( \Psi_0 \) only causes an offset in the angle of \( v_f \), as said in Subsection III-A, and does not affect its modulus. The cases with \( \Psi_0 = -90^\circ \), \( 0^\circ \) and \( 90^\circ \) in Fig. 1a correspond to the examples of Table I and Table II.

Fig. 1b shows the \( \Psi_0 \) influence on the anti-transformation of a given voltage \( v_f \). It is observed that the same voltage \( v_f \) can be related to a type D sag (for \( \Psi_0 = 0^\circ \) or \( 180^\circ \)), type C sag (for \( \Psi_0 = -90^\circ \) or \( 90^\circ \)) or other non-defined sags in Appendix I. As a consequence of this similarity, it is expected that the dynamic behavior of the studied equipment owing to type C or D sags will be identical in transformed variables. This is studied in detail in Section V. In practice, the most common values for \( \alpha_a \) and \( \Psi_0 \) are
- \( \alpha = 0^\circ \), which implies that \( V_a \) is the angle reference for all phasors.
- \( \Psi_0 = \alpha = 0^\circ \), which implies that the pre-fault voltage \( v_f \) is the angle reference for all transformed variables.

**B. Grouping of Sag Types**

This subsection analyzes the characteristics of two sags which are different in abc phase variables but identical in transformed variables. Let us assume two unsymmetrical sags 1 and 2, whose positive- and negative-sequence voltages are

\[
\begin{align*}
L_p^{(1)} &= V_p^{(1)} \angle \phi_p^{(1)} \\
L_p^{(2)} &= V_p^{(2)} \angle \phi_p^{(2)} \\
L_n^{(1)} &= V_n^{(1)} \angle \phi_n^{(1)} \\
L_n^{(2)} &= V_n^{(2)} \angle \phi_n^{(2)}
\end{align*}
\]

(5)

According to (3), both sags have identical transformed voltages \( v_f^{(1)} \) and \( v_f^{(2)} \) (i.e., they have identical moduli and angles with identical time evolution) for

\[
\begin{align*}
L_p^{(1)} &= V_p^{(1)} = V_p^{(2)} = V_p^{(2)} \\
L_n^{(1)} &= V_n^{(1)} = V_n^{(2)} = V_n^{(2)}.
\end{align*}
\]

(6)

If only the first three relations in (6) are satisfied, \( v_f^{(1)} \) and \( v_f^{(2)} \) differ in one offset angle. This is the case when considering the transformer connections in sag modeling (Subsection III-A). If the first two relations in (6) are satisfied but the third is not, the time evolution of \( v_f^{(1)} \) and \( v_f^{(2)} \) (modulus and angle) is the same apart from a time shift \( \Delta \phi \) as
respectively, and in (8). The same is true for the types A1-A2, A5-A4 and F2-G2 sags in Appendix II, whose time shift is $\Delta \varphi = 90^\circ$ in all cases. These time shifts correspond to differences between the fault-clearing instants $t_{f1}^{(1)}$ and $t_{f1}^{(2)}$ of Appendix II and can be mathematically written as

$$y_i^{(A_1)}(t) = y_i^{(A_2)}(t + t_{f0}) \quad y_i^{(D)}(t) = y_i^{(C)}(t + t_{f0})$$

$$y_i^{(A_5)}(t) = y_i^{(A_4)}(t + t_{f0}) \quad y_i^{(G)}(t) = y_i^{(F)}(t + t_{f0})$$

$$y_i^{(F_2)}(t) = y_i^{(G_2)}(t + t_{f0}),$$

where $t_{f0}$ is $1/4$ of a period. Note that type G1 and F1 sags evolve into type D and C sags, respectively, during fault clearance (see Appendix II) which, in turn, are also described in Appendix II, whose time shift is $90^\circ$ in the type A1 and A2, A5-A4 and F2-G2 sags.

As the simplification of considering or ignoring the transformer connections in sag modeling are the same, the next section focuses on the second approach (resulting in a time shift) in order to illustrate the grouping of sag types.

V. TIME-INVARIANT EQUIPMENT

In system theory, a dynamic system is called time-invariant (TI) if time-shifting the system input leads to an equivalent time shift in the system output with no other changes [4]. This idea is mathematically expressed as

if $u(t) \rightarrow y(t)$, then $u(t-\tau) \rightarrow y(t-\tau), \quad (9)$

where $u(t)$ and $y(t)$ are the system input and output, respectively, and $\tau$ is the time shift.

Let us define TI three-phase equipment: dynamic three-phase equipment (connected to a balanced network and operating in sinusoidal steady state) is called TI if the transformed voltage pairs in (8) lead to identical dynamic behavior with the only change of a $90^\circ$ time shift in the equipment variables.

In practice, TI equipment is easily recognized if it meets the following three conditions:

(I) The pre-fault dynamic three-phase electrical variables (i.e., the three-phase currents and/or fluxes) are constant if they are expressed in Park or Ku variables in the synchronous reference frame. Note that it is not required to solve the equipment equations in this reference (any reference is valid).

(II) If the equipment is controlled (i.e., power inverters and active rectifiers), the control strategy is carried out in Park or Ku variables, not in abc phase variables.

(III) There is no neutral connection (i.e., the zero-sequence voltage does not influence equipment behavior).

Note that the dynamic and control variables related to three-phase magnitudes must be expressed in transformed variables.

In system theory, the transformed voltages in (8) are the TI equipment inputs, while the equipment variables are the outputs whose time shift can be mathematically written as

$$\Delta \varphi = (\varphi_i^{(1)} + \varphi_i^{(1)}) - (\varphi_i^{(2)} + \varphi_i^{(2)}). \quad (7)$$

This is the case when ignoring the transformer connections in sag modeling (Subsection III-B): e.g., $\Delta \varphi = 90^\circ$ in the type D (or B) and C sags in Table II. This is also true for the type A1 and A2, A5 and A4, G1 and F1, and F2 and G2 sags in Appendix II, whose time shift is $\Delta \varphi = 90^\circ$ in all cases. These time shifts correspond to differences between the fault-clearing instants $t_{f1}^{(1)}$ and $t_{f1}^{(2)}$ of Appendix II and can be mathematically written as

$$y_i^{(A_1)}(t) = y_i^{(A_2)}(t + t_{f0}) \quad y_i^{(D)}(t) = y_i^{(C)}(t + t_{f0})$$

$$y_i^{(A_5)}(t) = y_i^{(A_4)}(t + t_{f0}) \quad y_i^{(G)}(t) = y_i^{(F)}(t + t_{f0})$$

$$y_i^{(F_2)}(t) = y_i^{(G_2)}(t + t_{f0}),$$

where $y$ stands for the dynamic variables and any other magnitude expressed in function of the dynamic variables, such as the instantaneous active and reactive powers or the electromagnetic torque in electrical machines.

According to (10), it is sufficient to consider five sag types for the study of sag effects on TI equipment, as types A1-A2, A5-A4, D-C, G1-F1 and F2-G2 cause the same time evolution in the transformed dynamic variables.

It is well known that the equations of three-phase induction and synchronous machines with linear magnetic characteristics are linear and time-invariant (LTI) in transformed variables at constant speed and only TI at variable speed. Similarly, averaged models for controlled power converters are usually only TI in transformed variables because of the dc-link voltage control loop. As a consequence, both types of equipment verify the above conditions I and II. Simulation has demonstrated that the following electrical equipment is TI, regardless of the use of Park or Ku variables and the reference frame:

- Three-phase induction (single-cage, double-cage, shorted slip ring or DFIG whose rotor control strategy is implemented in transformed variables) and synchronous (wound rotor or permanent magnet) machines whose output variables are three-phase voltages, currents and fluxes in transformed variables, rotor speed and position, electromagnetic torque, instantaneous active and reactive power, etc.

- Three-phase power inverter and active rectifier whose control strategy is implemented in transformed variables. The output variables are three-phase voltages and currents in transformed variables, dc bus voltage and current, instantaneous active and reactive power, etc.

- Three-phase passive equipment (linear transformers, capacitor banks, lines, cables and loads) whose output variables are three-phase voltages, currents and fluxes in transformed variables.

Note that the three-phase input/output/control magnitudes of TI equipment are considered in transformed variables (machine and network voltages, currents and/or fluxes). Obviously, the other magnitudes (rotor speed and position, dc bus voltage and current, etc.) are considered in actual values.

VI. SIMULATION EXAMPLES

In order to validate the study in this paper, three different grid-connected devices under sags are simulated with MATLAB and PSCAD: a three-phase induction generator, a three-phase inverter and a three-phase diode bridge rectifier. Note that only the first two are TI equipment.

A. Three-Phase Induction Generator

The 2.3 MW three-phase squirrel-cage induction generator of Table III, which is driven by a fixed-speed WT, is simulated. Fig. 2 shows the time evolution of the modulus and angle of the transformed stator current, $i_s$, the rotor speed, $\omega_m$,
and the electromagnetic torque, $T_e$, for the type $A_1$ and $A_2$, $D$ and $C$, and $G_1$ and $F_1$ sags.

As can be seen, the time evolution of $i_{sf}$ and $\omega_m$ corresponding to the grouped sag types ($A_1$-$A_2$, $D$-$C$ and $G_1$-$F_1$) is identical but time-shifted 90° in all cases. Then, the relations in (10) are satisfied. Note that this is valid not only for the machine dynamic variables (currents and speed), but also for the electromagnetic torque, which is expressed in function of the transformed variables.

### B. Three-Phase Inverter

A 0.1 MW grid-connected three-phase inverter whose parameters are given in Table IV is simulated. The generic structure of the synchronous reference frame control is considered [5]. Although the control is carried out in Park variables ($dq$ components), the simulation results are shown in $Ku$ variables (forward component) for clarity purposes. Fig. 3 shows the time evolution of the transformed current (modulus and angle), $i_t$, injected to the grid. Apart from the inverter switching commutations, it is apparent that the time evolution of the transformed current $i_t$ is the same but time-shifted when the inverter is under the grouped types ($A_1$-$A_2$, $D$-$C$ and $G_1$-$F_1$). Then, the relations in (10) are again satisfied.

It is worth noting that the use of an averaged model (neglecting the inverter switching harmonics) would provide an identical time evolution in the transformed currents of the grouped sag types (apart from the well-known time shift).

Finally, although the simple control structure of [5] does not contain independent controls for the positive- and negative-sequence currents occurring during the unsymmetrical sags, it is good enough to illustrate the similarities between the grouped sag types. As the results of this paper are valid for
any reference, even for the synchronous reference frame of the negative-sequence voltage, the inverters with independent 
controls for the positive- and negative-sequence currents [6]-
[8] exhibit identical behavior under the two grouped sag types.

C. Three-Phase Diode Bridge Rectifier

A three-phase diode bridge rectifier with three line 
inductors $L$ on the AC-side is simulated [9]. The DC-link 
consists of a capacitor $C$ connected in parallel to a constant 
current source $I_{dc}$. Its parameters and operating point are given 
in Table V.

TABLE V

<table>
<thead>
<tr>
<th>Nominal values</th>
<th>DC-link operating point</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_N$</td>
<td>$U_N$</td>
</tr>
<tr>
<td>10 kW</td>
<td>400 V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AC-line reactance</th>
<th>DC-link capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>$L$</td>
</tr>
<tr>
<td>0 Ω</td>
<td>1.9 mH</td>
</tr>
</tbody>
</table>

Fig. 4 illustrates the time evolution of the modulus and 
age of the transformed current, $i_f$, consumed from the 
network. Note that this device is not TI equipment as the 
transformed steady-state pre-fault current $i_f$ is not constant 
despite having used the synchronous reference frame.

As can be observed in the detail of Fig. 4a, the steady-state 
current $i_f$ takes different values at the initial instants $t_i$ of the 
type A1 and A2 sags, leading to different dynamic behaviors. 
As a summary, the time evolution of current $i_f$ is different for 
the grouped sag types (A1-A2, D-C and G1-F1).

VII. GROUPING FOR OTHER SAG MODELING APPROACHES

Fig. 5 shows three sag modeling approaches which differ in 
the choice of the voltage recovery instants, $t_{f1}$, $t_{f2}$ and $t_{f3}$. 
Fig. 5a illustrates the approach assumed in this paper, which is 
the most realistic as it takes into account the fault-clearing 
process (the fault is cleared at instants $t_{f1}$, $t_{f2}$ and $t_{f3}$ given in 
Appendix II [1]). Fig. 5c shows the most usual approach in the 
literature which, unfortunately, is the least realistic because it 
considers that the sag ends at any arbitrary instant (i.e., $t_{f1}$ can 
take any value) and that the fault clearance is abrupt (i.e., the 
fault is cleared instantaneously in all affected phases). As 
many current laboratory sag generators used for equipment 

testing are not able to emulate the approach in Fig. 5a, the authors propose the intermediate one in Fig. 5b. This approach considers that \( t_1 \) is discrete (see Appendix II) but the fault clearance is abrupt (i.e., the fault is cleared instantaneously in all affected phases). The sag grouping proposed for the approach of Fig. 5a (A1-A2, A3-A4, D-C, G1-F1 and F2-G2) is also valid for that of Fig. 5b. Regarding the approach in Fig. 5c, the grouping is reduced to sag types A, D-C and G-F, as there are no subtypes for the abrupt sag types A, F and G.

VIII. CONCLUSION

This study has shown that, among the fourteen discrete sag types in the literature, it is generally sufficient to consider only five types for the study of the effects of such disturbances on grid-connected equipment. This is because the following sag types cause identical behavior in Park or Ku transformed variables: A1-A2, A3-A4, D-C, G1-F1 and F2-G2. This means that when analyzing equipment behavior under voltage sags the number of simulations (or of laboratory tests) is reduced by an approximate ratio of three. This simplification is valid regardless of the reference frame and the use of Park or Ku variables.

The grouping is valid for time-invariant (TI) equipment, which is easily recognized because: (I) the pre-fault dynamic three-phase electrical variables (i.e., the three-phase currents and/or fluxes) are constant when expressed in the synchronous reference frame (although the grouping is also valid for any other reference frames), (II) in controlled equipment, the control is carried out in transformed variables, not in abc phase variables, and (III) the equipment has no neutral connection. Moreover, the grouping is applicable regardless of whether sags are modeled abrupt or discrete.

The grouping is valid not only for the transformed electrical variables (voltages, currents, fluxes, etc.), but also for the rotor speed, electromagnetic torque and rotor angle in the case of electrical machines, and for any other magnitudes which can be expressed in function of these variables, such as the instantaneous active and reactive powers.

REFERENCES