The Asynchronous Generator: Mirage in Electrical Engineering

A. H. R. KLIMANN

Abstract–The squirrel-cage asynchronous generator apparently offers many advantages; for example, high efficiency, a quickly damped short-circuit current, economy, reliability, and sparsity of related apparatus for regulation, control, and protection. It demands a large supply of reactive power, which can only be satisfied by the charging current of the power system with difficulty, because of the conditions to be met. There is, however, no great trouble in solving the problem, and preventing the danger of self-excitation; furthermore, all of the authors who have treated the subject are unanimously optimistic about it. This, together with the fact that the first suggestion to use asynchronous generators dates back to 1893, prompted the author to find out why only small quantities of them, of very small power ratings, have been installed in the world. The reasons are to be found in the phenomena which appear after a short-circuit in the power system, which justify the exclusive use of synchronous generators.

A long time ago I became interested in the asynchronous generator, whose in-depth study I could initiate only recently. At the beginning, I searched in the technical literature on my own, but later I received from Electricité de France a comprehensive bibliography, encompassing titles from 1953 on, for which I am deeply grateful.

The wound-rotor asynchronous generator is not generally considered, because it is more cumbersome and expensive than the synchronous generator. On the other hand, the squirrel-cage asynchronous generator offers many advantages [1]-[5]. Its efficiency at rated power, for a high synchronous speed, is greater than the one of an equally rated synchronous generator, and its supply of short-circuit current for certain types of faults is very quickly damped. Furthermore, it is also more economical because of its simpler construction and installation, easier maintenance, and greater service reliability, since it lacks excitation, windings on the rotor, synchronizing devices, voltage and frequency control, and some protective relays. It looks, therefore, ideal for small unattended hydro- and wind-power plants.

The greatest trouble, pointed out by all of the authors, is that this generator can supply energy only at a predetermined capacitive (leading) power angle between current and voltage, variable with the load. This reactive power can, however, be supplied by the charging current of the power system [2].

My first objection arose here, because a large uncompensated charging current, necessary at peak load if there are many asynchronous generators, would create large voltage differences in the system. This current should instead compensate the reactive component of loads, but be entirely suppressed at no-load.

Anyway, nothing prevents the installation of shunt capacitor banks in parallel with the asynchronous generators, the synchronous generators supplying the remaining with reactive power, as has been done in actual facilities. It is also possible to correct the other latent trouble, namely, self-excitation. Why, then, if all the problems have been solved, and the first contribution on the subject appeared in 1893 [3], have only a few squirrel-cage asynchronous generators of very small power ratings been installed?

These generators, after faults, have to be magnetically recharged (remagnetized) by parallel synchronous generators [4]. The unmentioned or insufficiently noted inconveniences are that the latter also become overburdened by the magnetic recharge of the induction motors of the load, without the proportional contribution of the asynchronous generators, and that, with both effects combined during a certain time, the greater the number or MW rating of the asynchronous generators, the greater the probability of voltage drops, swings, overloads, instability, and, consequently, of a total system breakdown.

Furthermore, it is not clear at all whether the asynchronous generator's ability to supply active power is impaired during magnetic recharging. This could be a nuisance or an advantage for stability, in accordance with its duration and the characteristics of the load and the synchronous generators. This problem has apparently been neglected, perhaps because the avalanche of reactive power after a short-circuit is already a deterrent.

So far the installation of asynchronous generators has been limited so that no great trouble has been reported because of them. But then, if they cannot work isolated they become uneconomic, and if they cannot be utilized in large scale they may be wholly overlooked.

I regret having studied the subject, because it was disappointing to have reached this negative conclusion. Since interest for it reappears periodically, I present this nonfeasibility, nonprogress report to prevent others from making the same mistake. Synchronous generators are here to stay.

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Instantaneous Three-Phase Reactive Power for Digital Implementation: Definition and Determination

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Abstract–Two methods of computing the instantaneous reactive power from concurrent samples of voltages and currents are suggested. The advantages are not having to wait for a quarter of a cycle, consistency with the active power computation, and a simple measurement of the deformation factor. Such a fast computation finds applications in protection, load behavior modelling, state estimation, reactive power compensation, etc.

I. INTRODUCTION

Qualitatively, one may define the reactive power as that portion of the power which loads the transmission system, with no contribution to the transport of energy. However, the exact definition of the reactive power has been a matter of opinion, convenience, and discussion [1]-[4]. The determination of the three-phase active and reactive powers digitally from the sampled (several times in a cycle) values of the instantaneous voltages and currents has applications in protection, load modelling, state estimation, reactive power compensation, etc. The conventional method [5] for active power computation involves the summing of the three instantaneous voltage-current products of each phase. The reactive power computation uses a signal delayed 90° in phase.

The inherent difficulties with this approach are 1) having to introduce a delay, 2) the imprecise determination of the delay if the frequency is fluctuating, 3) the reactive power determined no longer has the "snap shot" significance like the active power, due to the fact that measurements at two different instants are used, and 4) an inconsistency in the P and Q values can result since the former involves measurements at one instant and the later at two different instants of time.

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In this paper two computation schemes are proposed for the instantaneous reactive power which use the measurements at one instant only. These schemes are being used in load behavior modelling [6], [7].

II. REVIEW OF CLASSICAL DEFINITIONS

Let v_a, v_b, v_c be the instantaneous phase voltages; i_a, i_b, i_c be the instantaneous phase currents; V, I corresponding rms values; P, Q active and reactive powers.

A balanced sinusoidal systems may be written as follows:

$$v_a = \sqrt{2}\, V \sin \omega t \qquad i_a = \sqrt{2}\, I \sin (\omega t - \phi)$$

$$v_b = \sqrt{2}\, V \sin (\omega t - 120^\circ) \qquad i_b = \sqrt{2}\, I \sin (\omega t - \phi - 120^\circ)$$

$$v_c = \sqrt{2}\, V \sin (\omega t + 120^\circ) \qquad i_c = \sqrt{2}\, I \sin (\omega t - \phi + 120^\circ)$$

Normally the computation of the rms values are over a complete cycle. Thus:

$$V^2 = \tfrac{1}{3} [\overline{v_a^2} + \overline{v_b^2} + \overline{v_c^2}] \tag{1}$$

$$I^2 = \tfrac{1}{3} [\overline{i_a^2} + \overline{i_b^2} + \overline{i_c^2}] \tag{2}$$

$$P = [\overline{v_a i_a} + \overline{v_b i_b} + \overline{v_c i_c}] = 3VI \cos \phi \tag{3}$$

$$Q = [\overline{v_a i_a'} + \overline{v_b i_b'} + \overline{v_c i_c'}] = 3VI \sin \phi \tag{4}$$

where i_a', i_b', i_c' are current measurements delayed 90° in phase, and $\overline{}$ denotes averaging over a cycle.

III. INSTANTANEOUS EQUIVALENTS

In the case of a balanced sinusoidal three-phase system, the values computed by the following expressions at every instant do not vary during a cycle (i.e., are free from any oscillations) and are equal at every instant to the classical values computed from cycle averages. The principle feature here is the use of measurements at one instant only, even for the reactive power computation.

Voltage $$V^2 = \tfrac{1}{3} (v_a^2 + v_b^2 + v_c^2) \tag{5}$$

Current $$I^2 = \tfrac{1}{3} (i_a^2 + i_b^2 + i_c^2) \tag{6}$$

Active power $$P = v_a i_a + v_b i_b + v_c i_c \tag{7}$$

Reactive power (1) $$Q = \frac{1}{\sqrt{3}} [v_a(i_c - i_b) + v_b(i_a - i_c) + v_c(i_b - i_a)] \tag{8}$$

Reactive power (2) $$Q^2 = 9V^2 I^2 - P^2 \tag{9}$$

$$S_v = v_a + v_b + v_c \tag{10}$$

$$S_i = i_a + i_b + i_c \tag{11}$$

IV. NONSINUSOIDAL AND UNBALANCED SYSTEMS

It can be seen that the arithmetic mean of the (5), (6), and (7) over a cycle would yield expressions identical to (1), (2), and (3), respectively. Thus the rms voltage, current, and active power are unique even when the voltage and currents are distorted. The expression for Q^2 from (9) averaged over a cycle will represent a measure of the useless power (which loads the lines and has no contribution to the transport of energy). It can also be seen mathematically that, in case either the voltages or the currents are balanced and sinusoidal, the others being unbalanced but sinusoidal, the average of (8) over a cycle and (4) yield same values. In addition, when both voltages and currents are unbalanced and sinusoidal, the expression for reactive power from (8) yields a sum of positive and negative sequence reactive powers only, while (4) computes the sum of positive, negative, and zero sequence reactive powers. The two methods of reactive power computation illustrated here, in conjunction with the conventional method, can be used in detection and measurement of the nonsinusoidal nature and unbalance in three-phase systems.

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Corrections to "A Note on Partial Fraction Expansions"[1]

K. S. MILLER

Replace

$$[1/2\, k]$$

by

$$[\tfrac{1}{2}\, k]$$

in (8) and (18).

Replace

$$\begin{matrix} k+1 \\ 2i+1 \end{matrix}$$

by

$$\binom{k+1}{2i+1}$$

in (8).

The careful reader should be able to interpret the remainder of the paper without the modifications that were made by the author on the galleys but which were not made in the article as published.

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[1] K. S. Miller, *Proc. IEEE*, vol. 66, pp. 263–264, Feb. 1978.

Correction to "Specific Output of Windmills—A Discovery"

E. L. HARDER

There was an omission in the above letter.[1] The right side of equation (1) should include the factor 10^{-6}.

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[1] E. L. Harder, *Proc. IEEE*, vol. 65, no. 11, p. 1623, Nov. 1977.