

On Negative Power and Negative Power Factor in Alternating Current Power Systems

Some corrections to IEEE Standard 1459-2010

Alex McEachern, Fellow, IEEE

Power Standards Lab

Alameda, California, USA

Alex@McEachern.com – revised 3/2013

Abstract— In alternating current (ac) power systems, power is commonly defined as the rate of energy transfer. At most measurement locations on a grid, the energy transfer takes place in a single direction, typically from a source (such as a power grid) to a load (such as a house). But at certain locations, the energy transfers in opposite directions at different times, for example in the case of a house equipped with photovoltaic solar panels which may either accept power or deliver power to the grid. In these situations, it is common to measure negative power, that is, power flowing from the thing labeled as the load towards the thing labeled as the source. Negative power implies negative Power Factor. In IEEE Standard 1459-2010, there is an incorrect implication that negative power does not exist, and that therefore negative power factor does not exist. (The mid-20th century convention of arbitrarily using “+” or “-” to indicate Lead or Lag has caused further confusion.) IEEE 1459 should be revised.

Index Terms—power definitions, negative power, negative power factor, IEEE 1459

I. INTRODUCTION

In alternating current (AC) power systems, power is defined as the rate of energy transfer. At most measurement locations on a grid, the energy transfers in a single direction, typically from a source (such as a power grid) to a load (such as a house). But at certain locations, the energy transfers in opposite directions at different times, for example from/to a grid to/from a house equipped with photovoltaic solar panels. In these situations, it is common to measure negative power, that is, power flowing from the nominal load towards the nominal source.

Given that Power Factor is universally defined as the ratio between power and volt-amps, and given that volt-amps is always positive, we must conclude that when power is negative then Power Factor is also negative.

IEEE 1459 is causing confusion about these points for some users of this standard, and should be revised.

II. IEEE 1459 – SINGLE-PHASE UNDISTORTED POWER

IEEE 1459-2010[1] is “IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions.”

Negative power in AC power systems is a well-established and widely-accepted concept [2][3][4], but the 1459 Standard rather confusingly takes several different positions on the concept of negative power.

(The author of this paper, who helped edit both IEEE 1459-2010 and IEEE 1459-2000, accepts significant responsibility for the confusion.)

For simplicity, in this paper we limit ourselves to sinusoidal voltage and current on a single-phase circuit, which is discussed in Section 3.1.1 of IEEE 1459.

Section 3.1.1.1, Instantaneous Power, begins by defining power p in a conventional way:

$$p = p_a + p_q$$

where

$$p_a = VI \cos\theta [1 - \cos(2\omega t)] = P [1 - \cos(2\omega t)]; P = VI \cos\theta$$

$$p_q = -VI \sin\theta \sin(2\omega t) = -Q \sin(2\omega t); Q = VI \sin\theta$$

Note 1: The component p_a is the instantaneous active power...

There are no surprises here. Clearly V and I represent the root-mean-square value of the voltage and current, respectively, and are therefore positive. The $\cos\theta$ term can take any value between -1 and +1, so the value of power P can be either positive or negative.

However, Note 1 continues with a confusing statement.

NOTE 1—The component p_a is the instantaneous active power. It is produced by the active component of the current (i.e., by the component that is in phase with the voltage). The instantaneous active power p_a is the rate of flow of the energy... This energy flows unidirectional from the source to the load. Its steady-state rate of flow is not negative. $p_a \geq 0$. (underline added)

By limiting the production of p_a to the current component that is “in phase with the voltage”, this statement can be read to incorrectly imply that only positive power is defined. (The intent of this statement, the author believes, is to refer instead to the current component that is “not in quadrature with the voltage” which would include both the current that is in phase with the voltage, and the current that is 180° out of phase with the voltage, but would exclude the reactive power.)

The statement “...this energy flows unidirectional from the source to the load” is either a tautology, or incorrect in the real-world cases of residences with large photovoltaic arrays, grid-scale battery chargers/inverters, and many other modern “loads” in which the role of the “source” and the role of the “load” can and does swap quickly and often.



Fig. 1. A grid-connected 1.5 MW-hr lead-acid battery storage system located in Lanai, Hawaii. By convention, at the metering point between the storage system and the grid, power is positive when the grid is charging the battery, and power is negative when the battery (through an electronic inverter) delivers power to the grid. The system rapidly switches between these modes to support fluctuations in power output from an adjacent 2MW photovoltaic array.

The statement “(i)ts steady-state rate of flow is not negative, $p_a \geq 0$ ” is also confusing, in two different ways. First, p_a is the instantaneous active power, not the steady-state rate of flow. Second, the statement is simply untrue: p_a may be uniformly positive, or it may be uniformly negative. (The intent of this statement, the author believes, is that p_a is monosigned, i.e. if it is positive, it is always positive, and if it is negative, it is always negative, at least over a short term of time. It does not oscillate during a single fundamental period between positive and negative values.)

Unfortunately, these statements in IEEE 1459 have caused some readers to conclude that there is no such thing as negative power, and that the classic $P = VI \cos\theta$ formula for sinusoidal single-phase waveforms implicitly applies only to angles between -90° and $+90^\circ$. This conclusion is incorrect. IEEE 1459 should be clarified.

Adding to the confusion, IEEE 1459-2010 Section 3.1.3 concludes with a correct 4-quadrant chart that clearly and correctly shows both positive power and negative power.

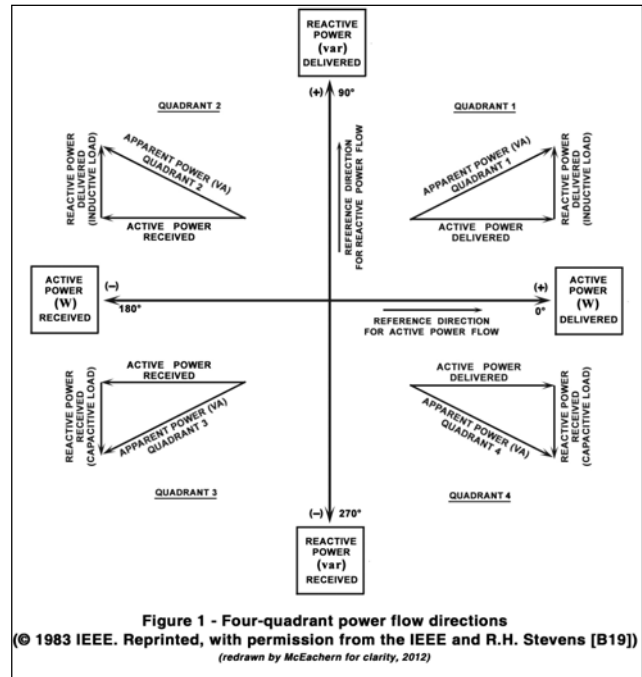


Fig. 2. IEEE 1459-2010 Figure 1 correctly shows negative power for single-phase, sinusoidal circuits, even though other parts of the text appear to say that negative power does not exist.

IEEE 1459 should be revised to clarify the definition of negative power.

III. NEGATIVE POWER FACTOR

Power Factor is universally defined as the ratio of watts to volt-amps. IEEE 1459-2010 uses this correct definition.

Volt-amps is the product of r.m.s. volts and r.m.s. amps. The square term in r.m.s. ensures that r.m.s. values are always positive. Therefore, when power is negative, Power Factor is, by definition, negative. When power is positive, Power Factor is, by definition, positive.

The concept of negative power factor as a consequence of negative power is widely accepted. [5]-[14]. Although IEEE 1459-2010 does not explicitly refer to negative power factor, it is an unavoidable consequence of the Power Factor equations in IEEE 1459-2010. Some readers, unfortunately, do not recognize the meaning of negative Power Factor (it simply means that the power is negative). When next revised, IEEE 1459 can assist those readers by making an explicit statement about negative Power Factor: that it exists, and that it simply means that power is negative.

IV. USING “-” AND “+” TO INDICATE LEADING AND LAGGING POWER FACTOR

Beginning in the early 20th century, it became common practice to use “-” and “+” to indicate leading or lagging power factor. The use of these symbols was purely arbitrary. The symbols did not carry the usual meaning of “less than zero”

and “more than zero”. Instead, they were used arbitrarily to indicate an angle.

Interestingly, there was no widely-accepted convention about which of these symbols represented leading power factor, and which symbol represented lagging power factor.

As pointed out by C. Bruce Campbell in [15], the Preface of the 4th Edition of Westinghouse’s Electrical Transmission and Distribution Reference Book, published in 1950, demonstrates the level of confusion about the meaning attached to “+” and “-”. The authors found it necessary to reverse course, twice, in successive editions. And ANSI Standard C12.16-1991 [16], Section 4.10 on Direction of Power Flow, essentially throws its hands in the air regarding the link between sign and lead/lag and says “Reference should be made to the manufacturer’s diagram.” As Campbell points out, this statement appears to leave selection of a sign convention entirely up to each manufacturer of each measuring instrument.

This practice of using “+” and “-” as arbitrary symbols has been widely replaced with explicit use of the terms “lead” and “lag” on meter displays. This replacement avoids the conflict with negative Power Factor discussed above, in which the minus symbol is not arbitrary at all: it carries the usual meaning of “less than zero”.

V. CONCLUSIONS

Negative power is a common, useful, and well-established concept in ac power circuits.

Negative Power Factor is a direct and unavoidable consequence of negative power.

“-” and “+” should not be used to indicate leading and lagging Power Factor. Those symbols should instead be reserved for indication negative and positive Power Factor.

When IEEE 1459 is next revised, it should be carefully edited to avoid confusion about the concepts of negative power and negative Power Factor.

ACKNOWLEDGMENT

I am grateful to two contributors to the Wikipedia.org article on Power Factor, W.T. Shymanski and Guy Macon, for their interesting and useful written discussion there, which triggered my preparation of this paper. Other contributors there were also useful, but anonymous, so I cannot give them credit. Any errors in this paper are, of course, my own. And, as has been the case for many, many years, I am grateful to Professor Alex Emanuel for his decades of kindness, wisdom and inspiration on the topic of power definitions.

REFERENCES

- [1] IEEE Std 1459-2010, “IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions,” IEEE, Parsippany New Jersey, 2010
- [2] L.A. Doggett and H.I. Tarpley, “Power and Energy, Positive and Negative,” *Trans. Amer. Inst. Elec. Eng.*, Vol. 54, Issue 11, pp 1204-1209, November 1935
- [3] E. So, P.N. Milanić D.J. Angelo, “A Computer-Controlled Load Loss Standard for Calibrating High-Voltage Power Measurement Systems,” *IEEE Trans Inst Meas*, Vol. 44, No. 2, pp 425-428. “Measurements can be made at any power factor from zero lag through unity to zero lead, positive or negative power...”
- [4] W.J.M. Moore *et al.*, “A Current-Comparator-Based System for Calibrating Active/Reactive Power and Energy Meters,” *IEEE Trans Inst Meas*, Vol. IM32, No. 1, pp 147-149. “Measurements can be made at ... positive or negative power...”
- [5] W. Duddell, “On the resistance and electromotive forces of the electric arc,” *Proceedings of the Royal Society of London*, pp. 512-515, 1901. “The fact that the solid arc has, at low frequencies, a negative power factor, indicates that the arc is supplying power to the alternator...”
- [6] N.P. Millar, “Expanded scale voltmeter”, U.S. Patent 2,788,491, April 1957. “...are more than 90 degrees out of phase, corresponding to a negative power factor condition...”
- [7] M. Fathizadeh, “Synchrotron Power Supply Light Source Note,” U.S. Gov. Contract W-3H09-ENG-38, LS-164, March 1991. “However, during the extraction, the power supply operates as an inverter which, therefore, delivers power to the utility. This action causes the negative power factor.”
- [8] L.H. Walker, “Power Conversion Scheme Employing Shorting Means to Control Current Magnitude”, U.S. Patent 5,091,840, February 1992. “Positive power factor represents power flow from the DC source to the AC source. Negative power factor represents power flow from the AC source to the DC source.”
- [9] S. Zhang, “Analysis of some measurement issues in bushing power factor tests in the field,” *IEEE Trans Pwr Del*, Vol 21 Issue 3, pp 1350-1356, July 2006. “...*(the measurement)* gives both negative power factor and negative resistive current (power loss).”
- [10] A.F. Almarshoud *et al.*, “Performance of Grid-Connected Induction Generator under Naturally Commutated AC Voltage Controller,” *Electric Power Components and Systems*, Vol 32, Issue 7, 2004. “Accordingly, the generator will absorb active power from the grid, which leads to negative power factor.”
- [11] N. Chilakapati, “Comparison of closed-loop speed control schemes for a doubly fed twin stator induction motor drive,” *Proc. of the Third International Power Electronics and Motion Control Conference*, vol. 2, pp 786-791, 2000. “It is to be noted that, a positive power factor denotes positive power input to the control winding while a negative power factor denotes power regeneration from the control winding.”
- [12] D.G. Oteman *et al.*, “System and Method for Controlling Power Balance in an Electrical/Mechanical System”, European Patent EP2345147, filed October 2009. “If $\cos\theta$ is negative, power factor is negative, and there is regeneration current on the system...”
- [13] L.U. Anih *et al.*, “Analytic synthesis of a hysteresis motor,” *Energy Conversion and Management*, Vol 52, Issue 1, pp 391-396, January 2011. “This means negative power factor or that electric power flows out of the machine from rotor to the stator resulting in generator operation, a reversal of power flow...”
- [14] R. Reginatto and C. da Rocha, “Influence of control strategies on DFIG-based Wind Farms integration in the power systems,” *Proc. XVIII Congresso Brasileiro de Automática (English)*, pp 2570-2576, September 2010. “In this case, a negative power factor means that the wind farm is absorbing reactive power from the grid...”
- [15] C.B. Campbell, “More Discussion of the Terminology of Alternating Current Power,” *Power Engineering Letters, IEEE Power Engineering Review*, July 1999

[16] ANSI C12.16-1991, "Solid-state Electricity Meters," American National Standards Institute, New York, NY, 1991.