WIND-POWERED ASYNCHRONOUS AC/DC/AC CONVERTER SYSTEM

D. K. Reitan

University of Wisconsin
Madison, Wisconsin

The two asynchronous ac/dc/ac systems shown in figures 1 and 2 are in the process of being modelled at the University of Wisconsin. The figures contain the main information and are somewhat self-explanatory such that only a brief explanation is contained herein. The system of figure 1 can use a variable or constant Hertz alternator drive such as can be provided by wind power. The system of figure 1 generates (ref. 1) variable Hertz ac, rectifies this with a frequency independent three-phase two-way, six-pulse bridge-rectifier (see inset) operating with constant current control, and parcels this constant I_R among pumped-storage, dc loads, and the high-capacity 60-hertz bridge inverter, also operating usually under constant current control (C.C.C.). The 60-hertz bridge inverter comprises a stable link to the power company to either supplement them from wind energy, storage, or from a combination of both at a preset desired current. In that the rectifier and inverter are identical, they are "converters" and can operate in either mode depending on the silicon-control-rectifier (SCR) firing angle α. Thus, if needed, the inverter can go over into rectifier mode and pump back into storage. Tests were run at a wide range of wind-bus hertz and with rectifier C.C.C. set at higher and lower levels than the inverter C.C.C. - storage taking up the slack. The system is not "sensitive" in that, for given C.C.C. settings, Sw3 can be opened and closed at will - suddenly - activating or cutting off the inverter current to the 60-hertz power company bus. The system is presently modelled as a three-phase ac generation/dc/three-phase 60-hertz inversion, but a single-phase 60-hertz C.C.C. inverter will be built also.

The system of figure 2 employs the same rectification but from a 60-hertz alternator arrangement (refs. 2 to 4). This system is missing the high-power 60-hertz inverter tie to the large backup supply of the power company, and it is thus meant to be a self-contained electric supply. System 2 has the option of mainly dc output, some sinusoidal 60-hertz from the wind bus and some high harmonic content 60 hertz from the 800-watt inverter. Work is presently under way to do some wave shaping on inverters of this type to investigate the harmonic tolerance of various appliances (ref. 5).

Figures 3 to 8 are mostly self-explanatory and show the instantaneous waveforms of voltage found at the indicated places in figure 1. Of note are the following:

(1) "Zero" voltage exists during conduction of an SCR.

(2) The "safe" negative, but large, voltage exists across a rectifier SCR during its off period.

(3) The potentially troublesome large positive voltage (shown in fig. 7) exists on an inverter SCR during its off time.

(4) The harmonic content in the bridge voltages increases in all cases when both the SCR firing angle and commutating angles are greater than zero.

(5) The firing angle of an inverter SCR must be such that the conduction period ($120^o + \mu$) is over soon enough to allow the deion angle γ or a commutation failure will occur. This is the reason for the build-in inverter constant extinction angle control (C.E.A.), which will override the inverter C.C.C. when necessary.

(6) Every commutation between a pair of SCR's momentarily results in a direct short circuit on one of the line-line voltages (fig. 8). For example (see inset, fig. 1), a commutation from SCR#1 to SCR#3 causes a short on line-line voltage E_{ab} for a duration of μ. The firing order of the converter shown is 1, 6, 3, 2, 5, 4.

Figure 9 shows the input and output of a six-pulse bridge-rectifier as supplied by a 100-percent field-modulated alternator (refs. 2 to 4). Pertinent operation is evident or noted directly on figure 9.

REFERENCES

1. Clews, Henry: Electric Power from the Wind. Solar Wind Company booklet and brochures on wind generators, RFD 2, East Holden, Maine 04429.

2. Bernstein and Schmitz: Variable Speed Constant Frequency Generator Circuit Using a Controlled Rectifier Power Demodulator. AIEE, Paper No. CP60-1053, San, Diego, Calif., Aug. 1960.

3. Allison, Ramakumar, Hughes: A Field Modulated Frequency Down Conversion Power System. IEEE Industry Applications Meeting Philadelphia, Pa., Sept. 1972.

4. Lindsley, E. F. and Luckett, H.: New Alternator Delivers 60-Cycle Power at Any Speed. Popular Science, Jul. 1973, page 38.

5. Grateful acknowledgment to the Sperry Univac Corp. and the Univ. of Wisconsin Research Committee for their encouragement and support to continue this project.

DISCUSSION

Q: With the rectifiers you were describing, is it possible to charge two frequencies?

A: No. I had a little 14-pole generator; 14 poles develops 60-cycles at 514 rpm. I ran it over 5000 rpm and operated it with no delay and with delay. The rectifier is independent of the frequency. It will pump into storage constant current control. All solid state controls will operate at that frequency.

Q: We found the converters were extremely expensive.

A: They are expensive, but I would like to add that this inverter-converter scheme, this particular graph's type bridge, is what's used in the present-day, large-scale dc power links. There are a dozen or so operating within the world, and there is practically no limit on the size of these converters. With the present state of the art, this rectifier and this inverter can be built for 3000 megawatts.

Q: I believe this solves the problem of the variable at one speed.

A: The rectifier is independent of the frequency. The inverter will operate strictly at 60 cycles and tie right onto the existing supply.

Q: Is that generally cheap in a system - are there any hydraulic variations?

A: I'm assuming that somebody can supply the proper wind generator, and I take it from the electrical end.

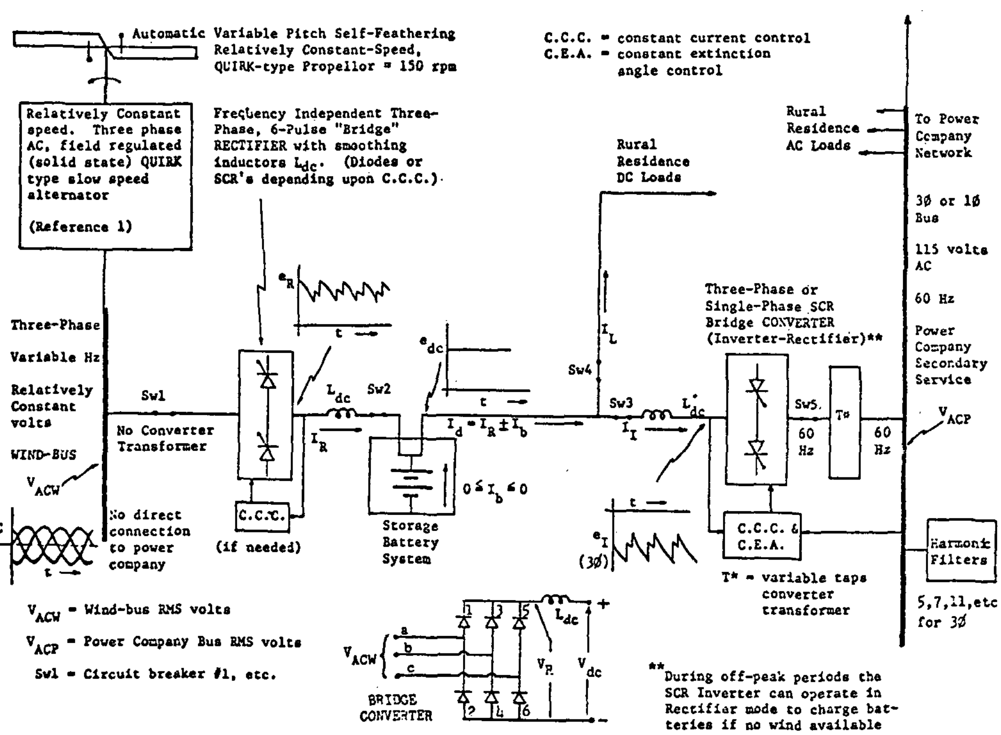

FIGURE 1. Non-Synchronous AC/DC/AC Pumped and Pumpback Storage Wind-Energy System to Supplement Rural Power Company Supply

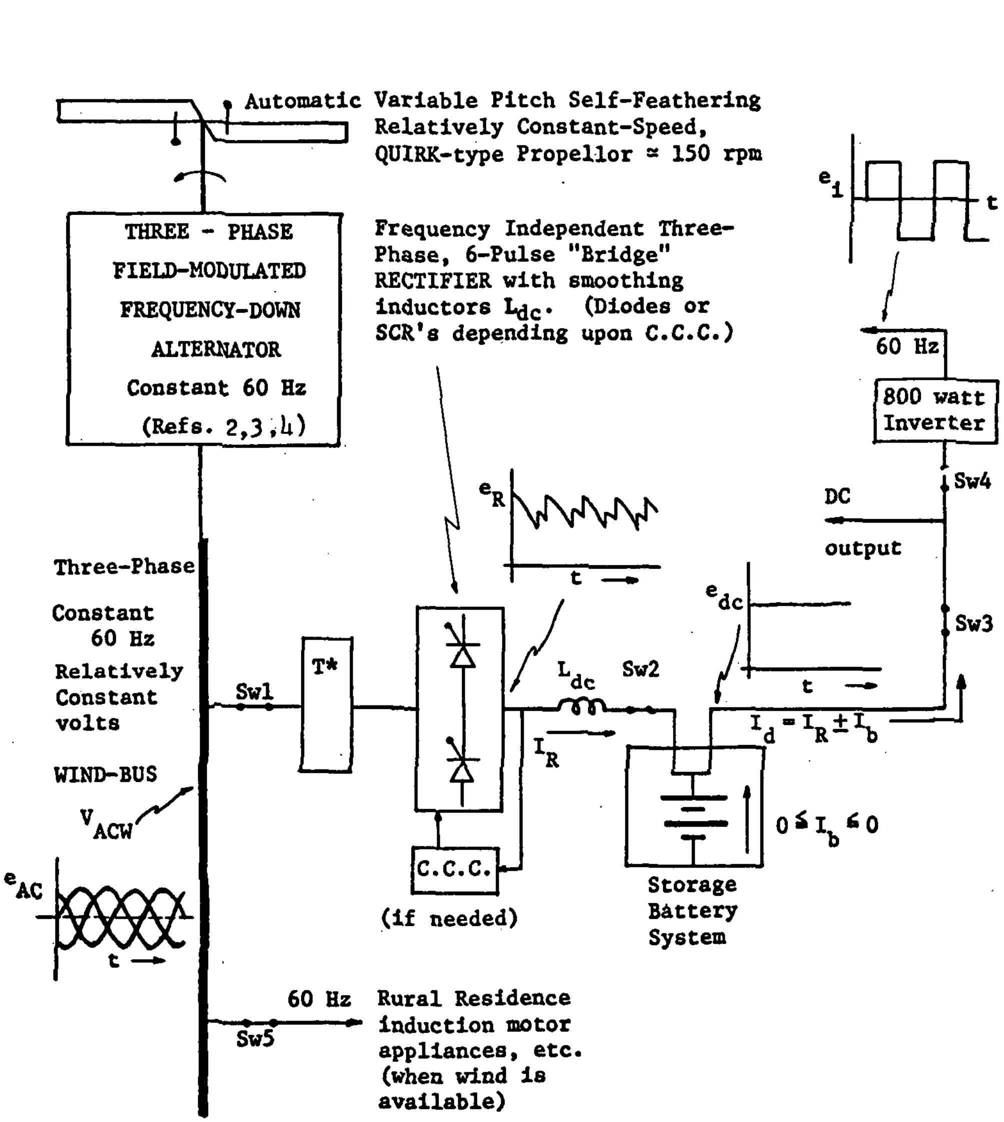

FIGURE 2. Non-Synchronous AC/DC/AC Pumped Storage Wind-Energy System for Electrically-Isolated Rural Residence

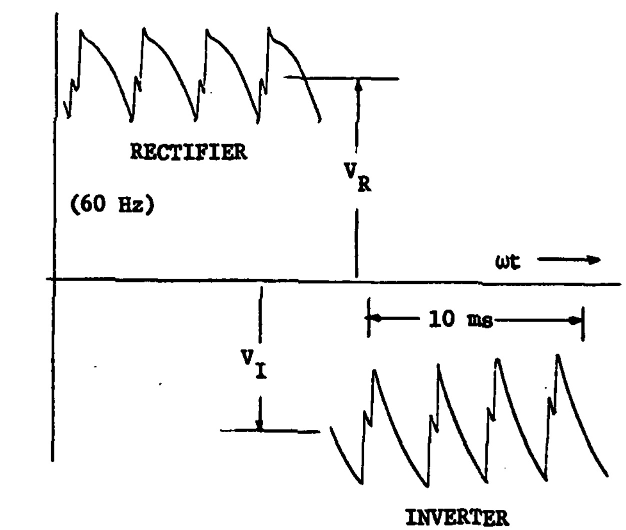

FIGURE 3. Full-Load Converter Bridge-Voltage

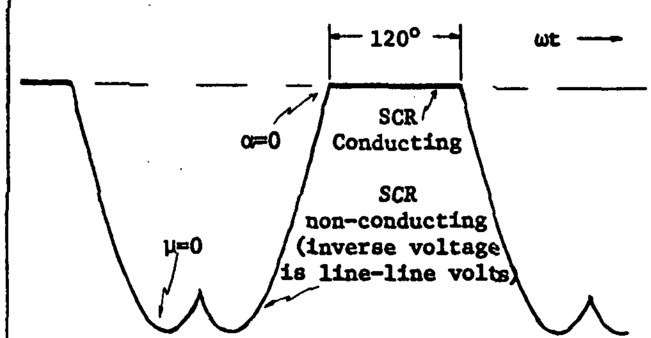

FIGURE 4. No-Load Rectifier SCR Voltage

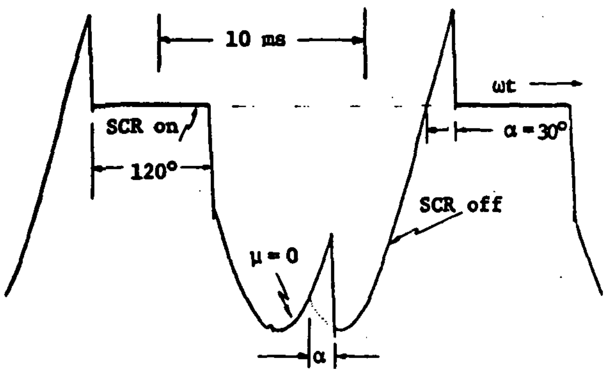

FIGURE 5. No-Load Rectifier SCR Voltage $\alpha \neq 0$

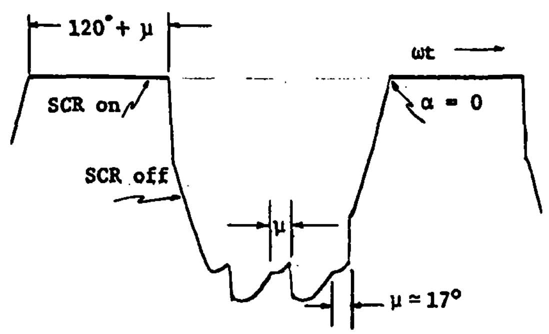

FIGURE 6. Full-Load Rectifier SCR Voltage
$\alpha = 0 \quad \mu \approx 17°$

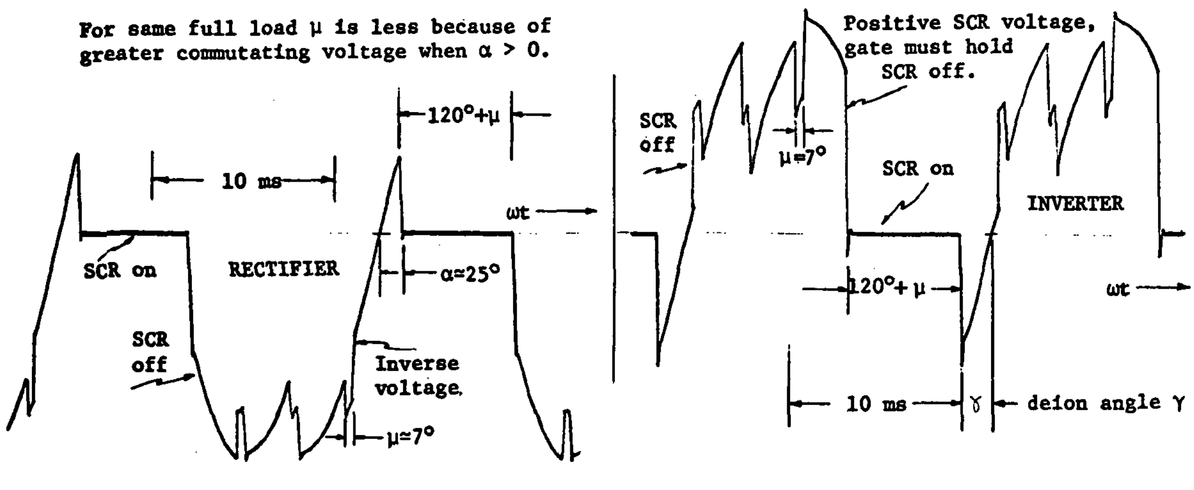

FIGURE 7. Full-Load Converter SCR Voltage — $\alpha \approx 25°$, $\mu \approx 7°$

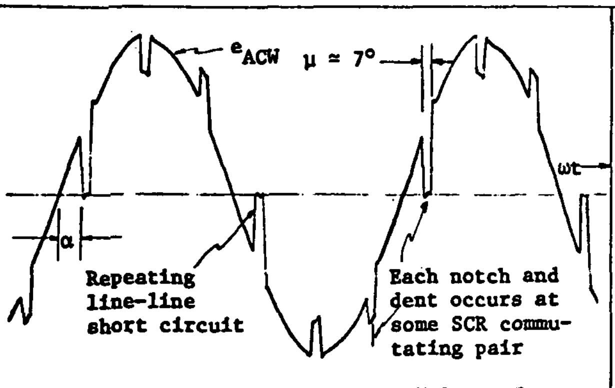

FIGURE 8. Full-Load Line-Line Voltage V_{ACW}

Remarks: 1. The system of Fig. 1 operates in a normal manner with rated V_{ACW} on the wind-bus and rated V_{ACP} on the Power Co. bus, for any level of Storage Battery System bus voltage from 10% to 100% of normal. The operation for lower Storage bus voltages merely changes to larger firing angle α and a different C.C.C. setting for the same constant current.

2. For low Storage bus-voltage (due to temporary partial outage) the harmonic content increases, the SCR voltages go lower and shift to the left in all the above figures, and the volt-ampere-reactive requirement of both AC busses unfortunately increases. This would be a temporary situation, usually.

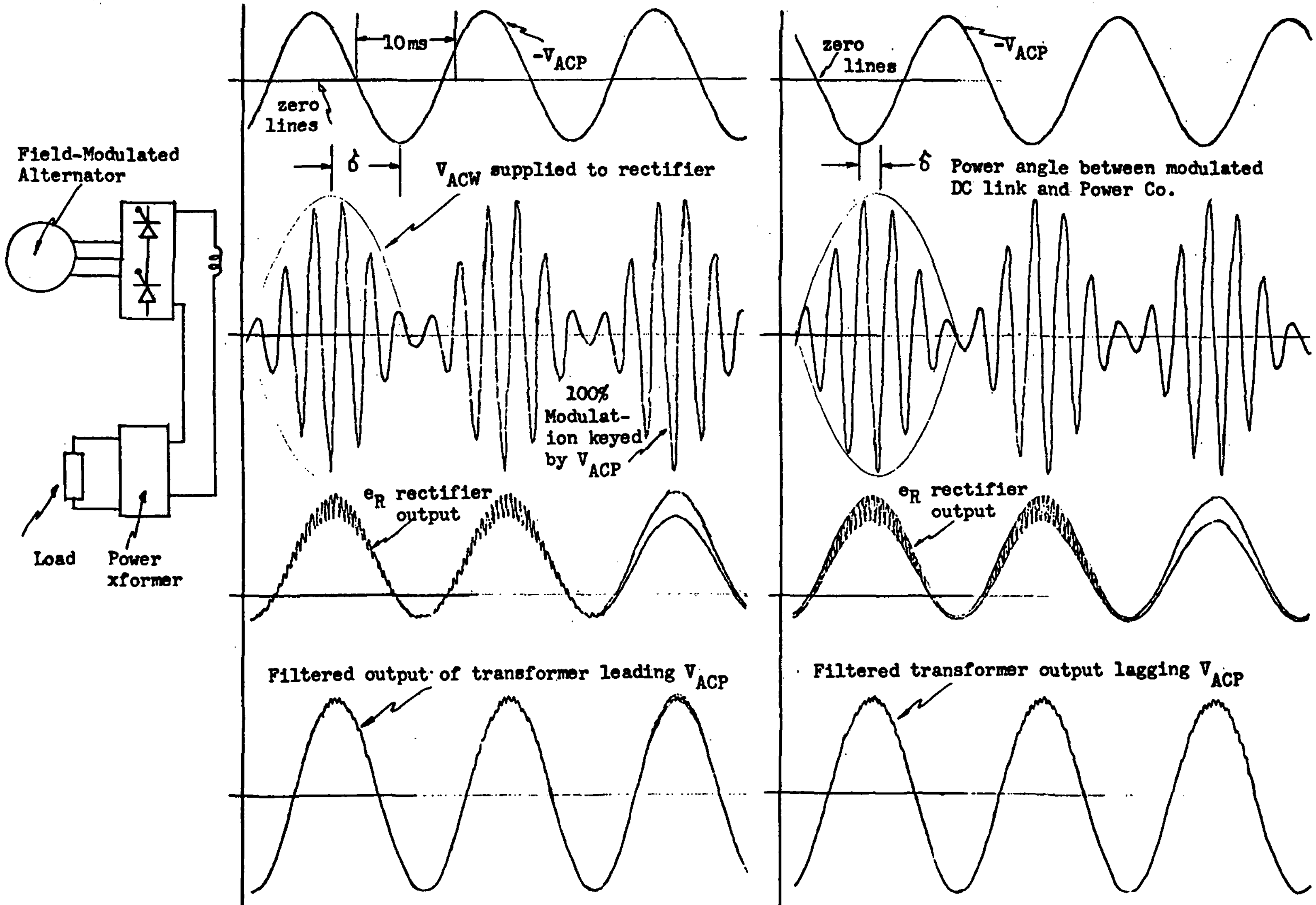

FIGURE 9. Six-Pulse Bridge Rectifier Operating From a Field-Modulated AC Alternator.