Power Factor Adjustment of a Grid Tie Power Electronics Using a Sensorless Control Algorithm in Organic Rankine Cycle Power Generation System

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Summary

This whitepaper describes the procedure and results of a power factor control technique developed for the grid tie Power Electronics (PE) that uses a sensorless control algorithm in an Organic Rankine Cycle (ORC) power generation system. The test results validated that the PE can adjust the power factor from 0.7 to 1.0 for both leading and lagging cases for different output power levels.

Background

The power factor is a ratio of active power over apparent power. Power factor adjustment is desirable and sometimes required for large grid connected power generating systems to reduce the risk of increasing the local grid voltage under certain circumstances. The power factor specifications for the ORC power generation system is typically determined by the utility infrastructure companies, depending on the structure of the distributed grid system.

Calnetix Technologies developed a power factor control feature for the PE to satisfy the local requirements of a Thermapower™ ORC system. The electric utility companies in the market required ORC units to have specific power factors on the power output of the ORC system. The intention was to reduce the risk of surging the local grid voltage under certain load conditions.

Calnetix's Vericycle™ bidirectional PE that has a hardware configuration consisting of grid side and machine side inverter modules. These modules are interconnected by a DC link capacitor. In the application with the Thermapower™ ORC system, a Carefree™ Integrated Power Module (IPM) generates electrical power from the expansion energy captured from the working fluid. The generated power voltage and frequency are then adjusted by the PE to meet the real time conditions of the three-phase grid that connects to the ORC unit.

In a normal AC system, the power factor is a measurement of the phase angle difference between the voltage and current. It is represented by the cosine of the angle of this phase difference. The PE is designed to minimize the phase difference between its output current and grid voltage to make the power factor close to unity. The power factor function of the PE can manage only the three-phase balanced power at the PE output to the grid. The power factor is defined as lagging when the PE phase current is lagging the grid phase voltage, and leading when the PE phase current is leading the grid phase voltage. The power factor control function is to change the power factor from unity by making the PE phase current lead or lag the grid phase voltage according to the commanded power factor requirement.

When the power factor control function is enabled, the PE adjusts the phase difference between the grid phase voltage and phase current in order to produce reactive current in accordance with the commanded power factor. The amplitude of the reactive current from the PE is based on the amplitude of the active current and phase difference.

Test Methodology

The following test methodology describes a process whereby the power factor control function was tested to confirm the minimum settable power factor at the nominal grid voltage of 480V was achieved at various PE power output levels.

The functional block diagram of the PE is shown in Figure 1. K_1 is the main contactor and K_2 is the soft contactor that is used to limit the inrush current when initial power is on. Three line inductors at the grid side reduce the total harmonics distortion (THD). Two Digital Signal Processor (DSP) control boards are used for grid side control and motor side control. The grid side DSP maintains the DC bus voltage to 750V.

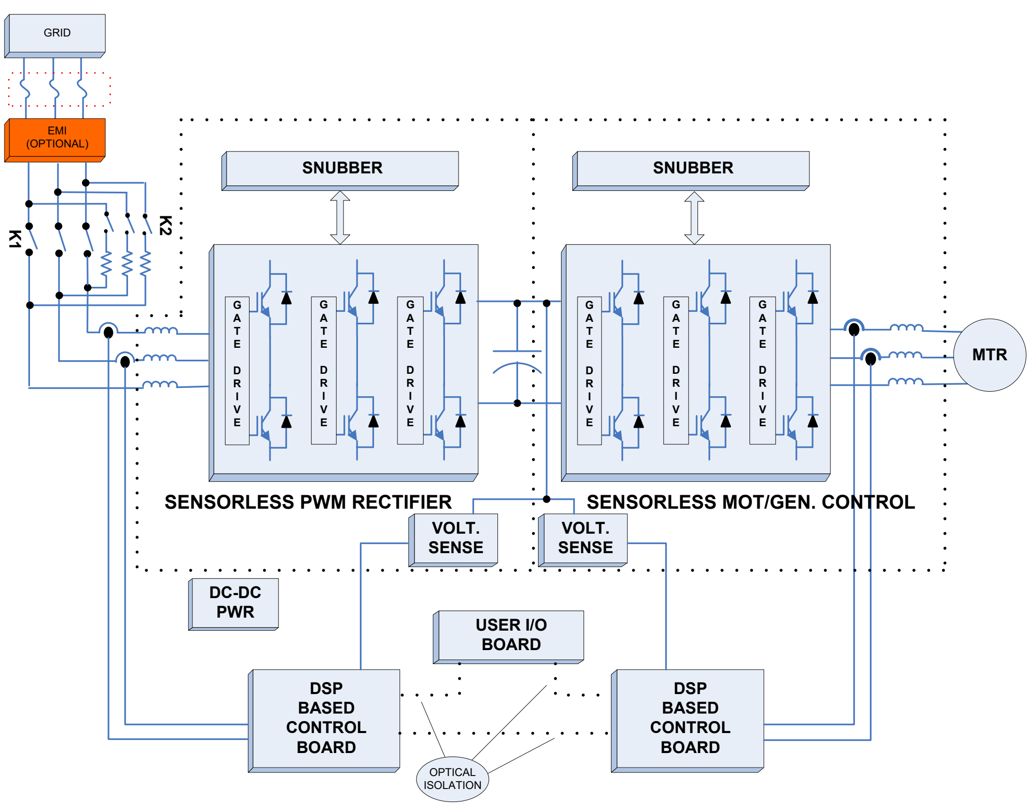

Fig 1. Function block diagram of the bidirectional PE.

The wiring schematic in Fig 2 shows the test set-up. A current probe was connected to each power line running between the grid and PE grid side inverter through a current transducer. An IPM was connected to the machine side of the PE. The ORC unit was commanded to produce various power output levels at multiple power factor set points. The PE output was analyzed using a Yokogawa WT1800 Power Analyzer.

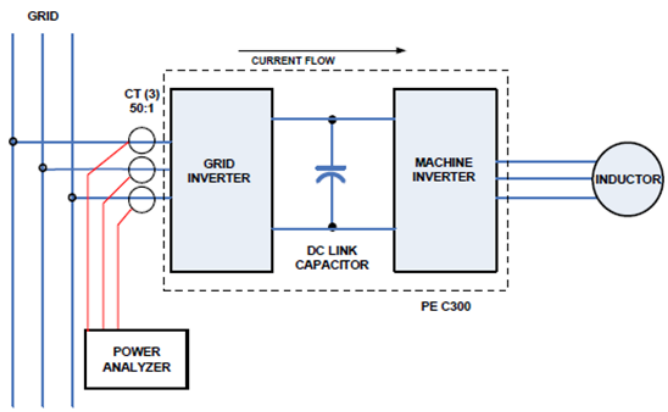

Fig 2. Wiring diagram.

Test Results and Discussion

Fig 3 is a screenshot of the power analyzer showing the test results when the ORC was commanded to produce 125kW with the power factor set point of 0.95.

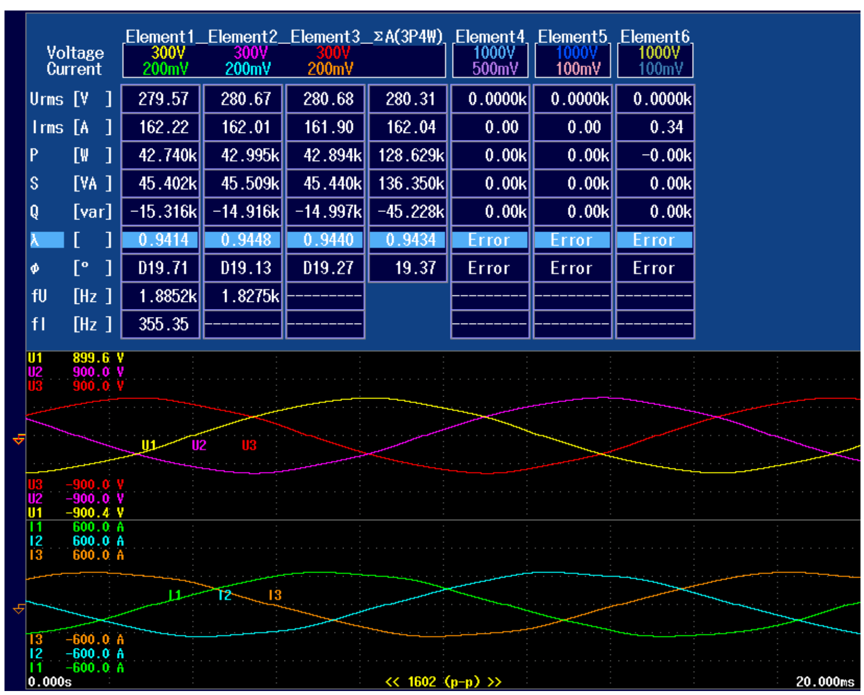

Fig 3. Power analyzer screenshot 1

The key measured values are shown below:

- The line to neutral voltage (Urms): 280.31V,
- The line current (Irms): 162.04A,
- The active power (P): 128.629kW,
- The apparent power (S): 136.350kVA,
- The reactive power: 45.228kvar,
- The measured power factor (λ): 0.9434,
- The measured phase difference between the line current and voltage (ϕ): 19.37 degrees.

The power was commanded to the motor side DSP with the assumption of 94% of efficiency. The actual output power of 128.6 kW was about 3% higher than commanded power because of the gain variation. With proper calibration, this error can be minimized. The measured power factor of 0.9434 was very close to the commanded power factor of 0.95. Fine tuning and calibration can provide greater improvement.

Fig 4 below shows the test results when the ORC was commanded to produce 90kW with the power factor set point of 0.95. Again, the output power of 95kW instead of 90kW was commanded because it was not well calibrated, but the measured power factor of 0.943 was very close to the commanded power factor of 0.95.

Fig 4. Power Analyzer Screenshot 2.

Table 1 shows measurement results at different PE power output levels with the power factor set point of 0.70, except for 125kW. The power set point of 0.75 was used to avoid exceeding the limit of the PE line current.

Table 1. Power Factor Measurement Results

ORC Power Output Command (kW)	PE Power Output (kW)	Power Factor Command	Power Factor measured, Leading or Lagging
50	50.983	0.70	0.6577, Leading
70	74.670	0.70	0.6662, Leading
90	91.638	0.70	0.6684, Leading
110	113.089	0.70	0.6735, Leading
125	129.266	0.75	0.7375, Leading

It was noted that the leading power factor can also be achieved by commanding a negative value of power factor to the controller.

Conclusions

The tests confirmed that the minimum settable power factor at the nominal voltage of 480V was achieved at various PE output levels.

Because of sensorless control (without grid voltage sensors), there is some error between the power factor command and the measured power factor. Further calibration of the power factor and output power will provide a more accurate power factor adjustment.

About Calnetix Technologies

Calnetix Technologies, LLC ("Calnetix"), headquartered in Cerritos, Calif., is focused on Innovation That Drives Industries™. The company specializes in high-performance, high-speed motor generators and best-in-class advanced magnetic bearings and control systems. Calnetix's patented, underlying technologies, which have been in use since the company's inception in 1998, have made Calnetix a world leader in the design and production of high-speed machines. The company's overall technology portfolio and system integration capabilities have led to development and production contracts with industry leaders and the start of many successful subsidiaries that focus on unique niche markets. For more information, please visit www.calnetix.com.