PERFORMANCE OF AN ELECTRONIC ENERGY METER

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ABSTRACT

In this paper the principle of operation, implementation and performance of an integrated circuit based electronic energy meter are described. Comparison is made of the performance of the electronic energy meter with that of the conventional electromechanical energy meter, on various loads of different power factors. The results suggest that the electronic energy meter performs better on non-linear loads, while the conventional meter performs better on linear loads. However, more accurate measurements eliminating as many errors as possible should be done before reaching any conclusion about the performance. It is suggested that a data logging system using a computer be used for more precise collection of data in further testing of the meter performance.

1. INTRODUCTION

The popular electromechanical watthour meter used for the measurement of electrical energy consumption is a motor mechanism in which a rotor element revolves at a speed proportional to the power flow and drives a registering device on which energy consumption is integrated. The conventional ac watthour meter measures energy by using the principle of the induction motor and the two main coils in the meter are fed with the voltage and the current at the consumer's terminals. The alternating fluxes in these two coils induce currents in an aluminum disk placed between them and the interaction of these currents and the fluxes creates the torque which rotates the disk. The resulting speed of rotation of the disk is proportional to the power consumed by the load measured in watts or kilowatts, and the number of rotations of the disk is proportional to the energy consumed given in watthours or kilowatthours.

This electromechanical energy meter has been in existence for a long period of time, serving the electric utility industry all over the world by measuring and registering the kilowatthours consumed at the place it is installed; the only duty it is traditionally required to perform. In the past few years however, with the decentralization and deregulation of the electric utility industry taking place in many countries, this traditional role played by the energy meter at the consumer's end also has begun to change. With the deregulation, the customer is encouraged to have a greater voice and the utilities are faced with new challenges to survive with the ever-increasing competition. The emergence of the electronic energy meter in this background replacing the conventional electromechanical meter has helped the utilities provide new metering solutions to its customers and thereby improve the quality of their services. Electronic energy meters can improve the customer service through additional features such as remote meter reading and power outage detection, in addition to the higher precision and the ability of providing load profile graphs and tables etc. when required. Another advantage of electronic energy meters to both utility and the consumer is their higher accuracy despite nonlinear loads that are becoming more common with the increased use of power electronic components. Some technical specifications of an electronic energy meter available in the market are given in the Appendix.

In this paper the principle of operation of the electronic energy meter is described. The performance of a prototype electronic energy meter built using the AD 7750 product-to-frequency converter integrated circuit (IC) is discussed in comparison with the performance of the conventional electromechanical energy meter.

2. PRINCIPLE OF OPERATION

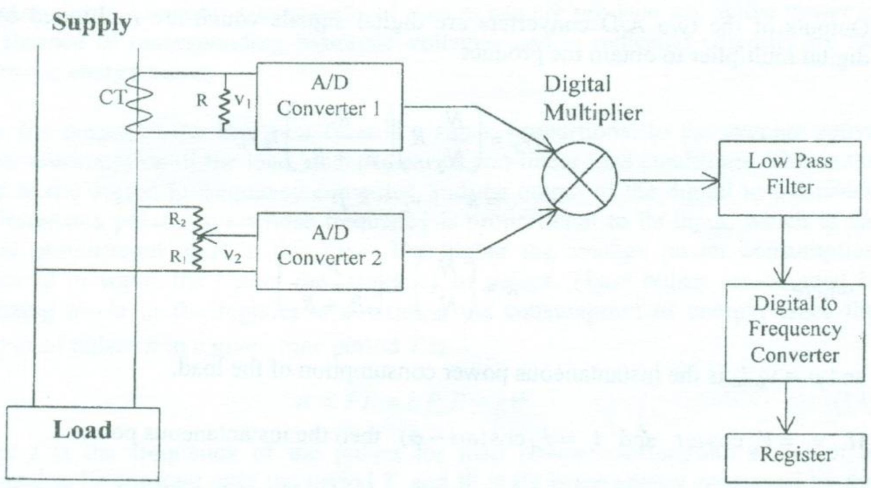

Figure 1. Functional block diagram of the electronic energy meter

As shown in Figure 1, main functional blocks in an electronic energy meter are two analog-to-digital converters, a digital multiplier, a low pass filter and a digital to frequency converter. The two parameters that are needed for measurement of power or energy, are the voltage applied to and the current drawn by the load. The load current is usually measured by a current transformer (CT) as shown. Alternatively, it may be measured by either using a shunt resistor or a hall effect device.

The voltage v_l across the burden R in the secondary of the current transformer can be expressed as

$$v_1 = i_2 R \qquad (1)$$

where i_2 is the current flowing out of the secondary of the CT which is related to the load current i_L in the primary of the CT by the equation

$$i_2 = \frac{N_1}{N_2} i_L \qquad (2)$$

where N_1 and N_2 are number of turns in the primary and the secondary of the CT respectively.

From (1) and (2), the voltage input to the A/D converter 1 is

$$v_1 = \frac{N_1}{N_2} R \ i_L \tag{3}$$

The voltage input to the A/D converter 2 is

$$v_2 = \left(\frac{R_1}{R_1 + R_2} \right) v_L \tag{4}$$

where v_L is the load voltage.

Outputs of the two A/D converters are digital signals which are multiplied by the digital multiplier to obtain the product

$$v_1 v_2 = \left(\frac{N_1}{N_2} R \right) \left(\frac{R_1}{R_1 + R_2} \right) i_L v_L \tag{5}$$

$$= k \ \ i_L v_L = k \ p \tag{6}$$

where

$$k = \left(\frac{N_1}{N_2} \right) R \left(\frac{R_1}{R_1 + R_2} \right) \tag{7}$$

and $p = v_L \, i_L$ is the instantaneous power consumption of the load.

If $v_L = V_m \cos \omega t$ and $i_L = I_m \cos(\omega t - \phi)$ then the instantaneous power

$$p = v_L \, i_L = V_m I_m \cos \omega t \cos(\omega t - \phi) \tag{8}$$

$$= V_{rms} I_{rms} [\cos(2\omega t - \phi) + \cos \phi \ ]$$

where, $V_{rms} = \dfrac{V_m}{\sqrt{2}}$ and $I_{rms} = \dfrac{I_m}{\sqrt{2}}$

Further simplification of equation (8) results in

$$p = V_{rms} I_{rms} \cos \phi \ + V_{rms} I_{rms} \cos(2\omega t - \phi) \tag{9}$$

The first term in equation (9) is a dc component and the second term varies cosinusoidally with time resulting in a zero average value. Thus the average value of p is the dc component

$$P = V_{rms} I_{rms} \cos \phi \tag{10}$$

which can be obtained by low pass filtering the output p of the multiplier as given in equation (8).

If the load current i_L contains any harmonic component, say n^{th} order, then equation (8) becomes,

$$p = v_L \, i_L = V_m \cos \omega t \ [I_{m1} \cos(\omega t - \phi_1) + I_{mn} \cos(n\omega t - \phi_n)]$$

$$= V_m I_{m1} \cos \omega t \cos(\omega t - \phi_1) \ + V_m I_{mn} \cos \omega t \cos(n\omega t - \phi_n) \tag{11}$$

The average value of the second term in equation (11) is zero, and therefore, the average power consumption P is the dc component of the first term given by,

$$P = V_{rms} I_{rms1} \cos\phi_1 \tag{12}$$

where, $I_{rms1} = \frac{I_{m1}}{\sqrt{2}}$ is the rms value of the fundamental frequency current, and $\cos\phi_1$ is the displacement power factor, the power factor associated with the fundamental frequency current and the voltage.

In other words, harmonic components of current can not produce any active power in the absence of corresponding harmonic voltages, and is indicated correctly by the electronic energy meter.

Thus the output of the low pass filter is a signal proportional to the average active power consumption of the load, under linear or non-linear load conditions. This is the input to the digital to frequency converter, and the output of the digital to frequency converter is a pulse wave whose frequency is proportional to its input, which is the signal proportional to P in this case. The higher the average power consumption measured in watts, the higher the frequency of pulses. These pulses are counted in totalizing mode in the register to determine the consumption of energy, since the number of pulses n in a given time period T is

$$n = fT = kPT = kW \tag{13}$$

where f is the frequency of the pulses for load power consumption P which is assumed to be constant over the period T, and $W = PT$ is the energy consumed by the load during this period. k is the meter constant. As can be seen from equation (11), the total number of pulses indicates the amount of energy consumed in kilowatthours when the meter is properly calibrated.

3. IMPLEMENTATION

A prototype electronic energy meter was constructed using the AD 7750 product-to-frequency converter IC [1]. The functional block diagram of the IC and its pin configuration are given in Figure A.1. It contains two analog-to-digital converters, a digital multiplier, digital filters and a digital-to-frequency converter, all of which are needed for the implementation of an electronic energy meter. The output of the IC can be directly connected to a stepper motor that drives a mechanical register, or to an electronic counter in totalising mode.

The two input channels of the AD 7750 IC are fed by two voltage signals proportional to the voltage and the current supplied to the load. Load voltage signal can be fed after attenuating it to a suitable value using a potential transformer (PT) or a potential divider. Load current signal is fed to the IC by using a shunt resistor, hall effect device or a current transformer (CT). The maximum values of the two analog input signals should be $\pm 1V$. The sampling frequency of the two input channels is approximately 900 kHz. The IC requires a single 5V power supply for its operation.

In addition to the pulse output for driving a stepper motor or a counter, there is also a high frequency pulse output for calibration purposes.

The current signal was fed to the channel 1 of the IC through a CT, while the voltage signal was fed through a potential divider. A three segment LED counter was constructed as the meter register to count the output pulses of the IC.

The net direct cost of the prototype meter was about Rs. 583.00 excluding the cost of labor, machinery, electricity and rent etc., and the breakdown is given in Table 1.

Table 1. Cost breakdown of the prototype electronic energy meter

Description	**Cost (Rs.)**
Current Transformer (CT)	120.00
AD 7750 IC	210.00
Resistors, Capacitors etc.	253.00
Total (excluding the counter)	**583.00**

4. METER PERFORMANCE

4.1 Testing at the CEB Meter Testing Laboratory

The accuracy of the meter was tested at the CEB Meter Testing Laboratory and the percentage errors at different loading conditions calculated as

$$Percentage\ Error = \frac{Energy\ registered\ by\ the\ energy\ meter - True\ energy}{True\ energy} \times 100$$

are given in Tables 2.1 and 2.2 below. The energy displayed at the test bench is considered as the true energy.

Table 2.1 Percentage error under different loading conditions

Power factor / Current (A)	Leading		1.0	Lagging	
	0.8	0.9		0.9	0.8
1.0	-0.96 %	0 %	0.96 %	1.92 %	1.92 %
5.0	-0.96 %	-0.96 %	-0.96 %	0.96 %	1.92 %
8.0	-0.96 %	-0.96 %	0 %	1.92 %	1.92 %

Table 2.2 Percentage error under different loading conditions

Current (A) \ Power factor	Leading 0.5	Leading 0.75	1.0	Lagging 0.75	Lagging 0.5
2.0	-3.85 %	-1.92 %	0.96 %	2.88 %	5.77 %
4.0	-3.85 %	-1.92 %	0.96 %	2.88 %	5.77 %
6.0	-2.88 %	-1.92 %	1.92 %	2.88 %	5.77 %
8.0	-4.81 %	-1.92 %	0.96 %	2.88 %	4.81 %

The above results show that the meter error increases with the decreasing power factor and is higher for lagging power factor loads than for leading power factor loads.

4.2 Energy measurement under different loading conditions

In order to compare the performance of the electronic meter with that of the conventional electromechanical meter, further testing of the meter was done with a varying loads for resistive, inductive and capacitive (both power factors = 0.8) loads. The speed of the meter in pulses per minute (ppm) is shown in Figure 2 for different power factor loads. It can be seen that the meter runs slightly faster under inductive loads, while it is slightly slower under capacitive loads, compared with its speed under resistive loads. The percentage errors of the electronic energy meter under different power factors, assuming the wattmeter reading to be correct are shown in Figure 3. For comparison, Figure 4 shows the error for the conventional electromechanical energy meter under the same load conditions.

4.3 Energy measurement of some commonly used loads

In order to compare the performance of the electronic energy meter with that of the conventional electromechanical meter on some commonly used loads, the performance of the two meters were tested on the following loads:

a) Incandescent lamp load b) Induction motor c) Computer load
d) Adjustable speed motor drive (ASD)

The results of the tests and the errors calculated assuming the wattmeter reading to be correct are given in Table 3. For the electromechanical meter, the time for a given number of revolutions was measured using the stopwatch and the watthour value was calculated from this reading using the meter constant. Similarly, for the electronic meter, the watthour value was calculated using its meter constant and the time for a given number of pulses.

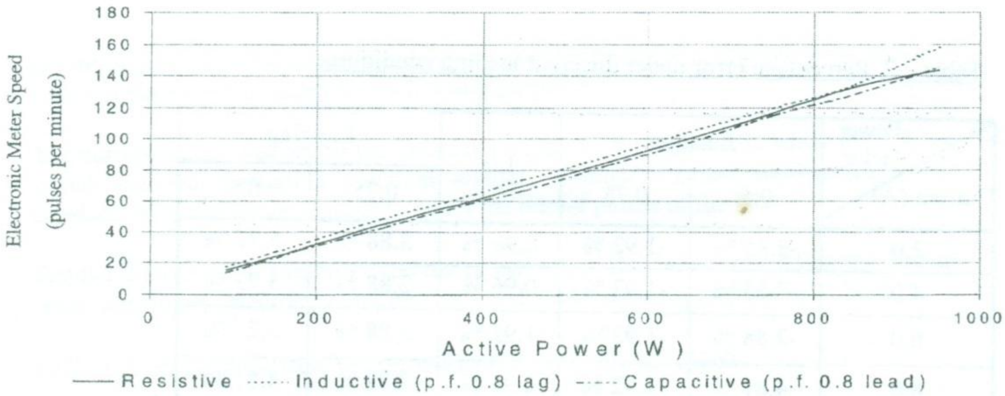

Figure 2. Speed of the electronic energy meter Vs active power for three power factors

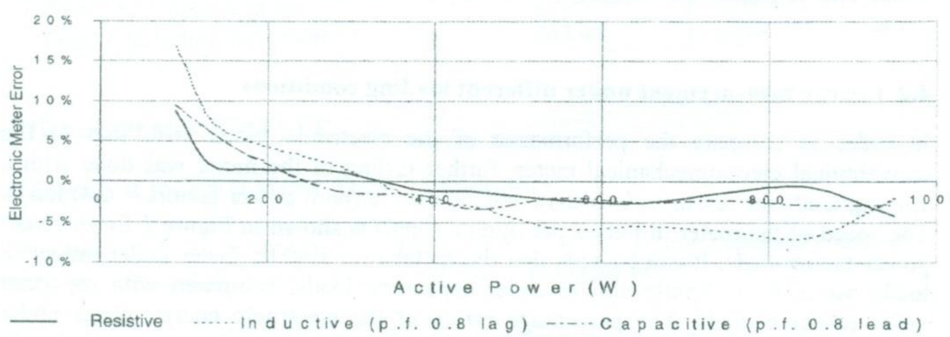

Figure 3. Percentage error of electronic energy meter Vs active power for three power factors

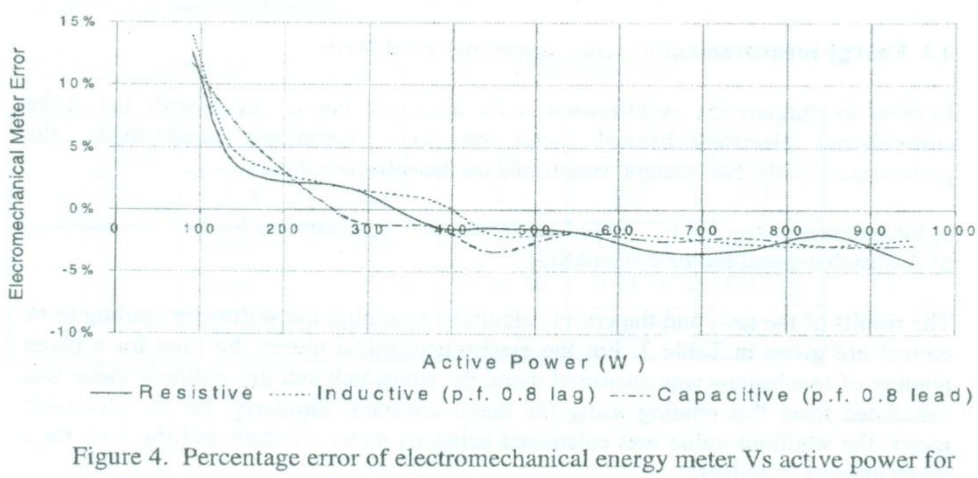

Figure 4. Percentage error of electromechanical energy meter Vs active power for

Table 3. Performance comparison of the two meters on some common loads

Load	Energy calculation based on Wattmeter reading (Wh)	Conventional energy meter reading		Electronic energy meter reading	
		(Wh)	Error	(Wh)	Error
Incandescent lamp load	123.88	123.75	-0.11%	122.84	-0.84%
Induction motor load	75.82	75.00	-1.08%	76.92	1.45%
Computer load	60.45	62.50	3.39%	59.13	-2.18%
ASD	81.68	82.53	1.04%	81.42	-0.32%

The voltage and the current waveforms of the above four loads are given in Figures A.2 to A.5. As can be seen from the figures, the incandescent lamp load and the induction motor are linear loads and the computer load and the ASD are non linear loads, taking currents in non sinusoidal manner.

From the results in Table 3, we can see that for non linear loads, the errors of the electronic energy meter are lower than those of the conventional energy meter, which is a major advantage expected from the electronic energy meter over the conventional energy meter. The accuracy of electromechanical watthour meter is known to be affected when operating under harmonic conditions [2][3]. Our experimental results indicate that for linear loads the errors of the electronic meter are higher and therefore, it is not possible to arrive at a conclusion on the accuracy of the two types of meters based on these readings alone. The major problem that is encountered here is the calculation of the actual energy usage especially under non-sinusoidal situations. The wattmeter reading had to be relied on which also may be in error due to the presence of harmonics. One way to overcome this is conducting a harmonic analysis which needs very accurate readings, and human errors have to be avoided as much as possible. A data logging system using a computer and subsequent harmonic analysis can minimize such errors and therefore, further testing with such facilities for accurate comparison of the two meters is suggested.

5. CONCLUSIONS

Electronic energy meters are rapidly being introduced to the market today, and in addition to the measuring and recording of the energy consumption, more advanced features such as data management and communication are also being incorporated into the meter itself. The prototype meter constructed is the lowest cost solution performing only the basic function.

The performance tests gave mixed results suggesting that the electronic energy meter performs better on non-linear loads, while the conventional meter performs better on linear loads. However, the conclusion is that more accurate measurements eliminating as many errors as possible should be done before reaching any conclusion about the performance. A data logging system using a computer is suggested to be used for more precise collection of data in further testing of the meter performance.

Another area which needs further attention is the current transformer (CT) used in the meter. The presence of harmonics in the current due to the non-linear loads has to be taken into consideration in the design of the CT.

The electronic energy meter has fewer moving parts than that of a conventional electromechanical energy meter and therefore, the need for periodic adjustments due to the wear of rotating parts etc. is much less needing less maintenance than the conventional meter.

Damage due to lightning surges is a major concern area for users of electronic energy meters and therefore, more research needs to be done in the area of lightning protection of electronic energy meters especially in the Sri Lankan environment.

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APPENDIX

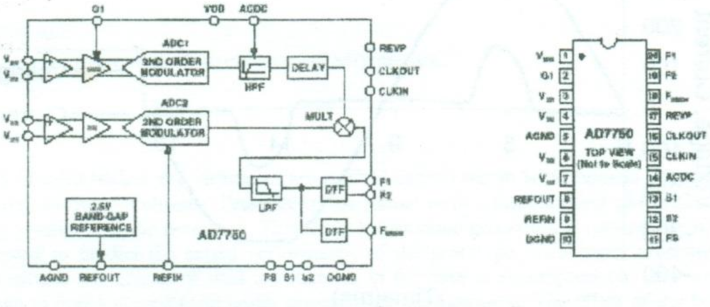

Figure A.1 Functional block diagram and the pin configuration of AD 7750

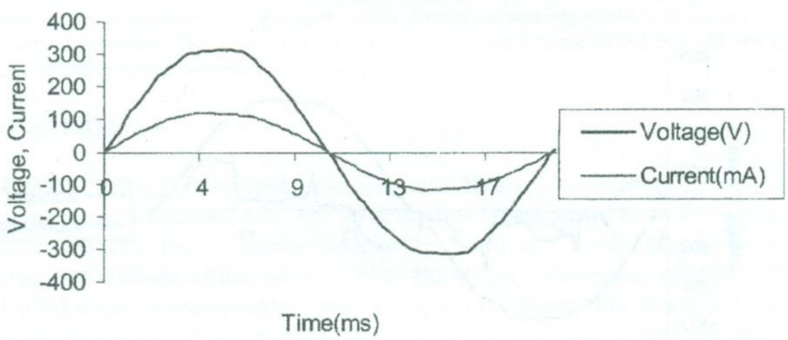

Figure A.2 Input voltage and current waveforms of an incandescent lamp load

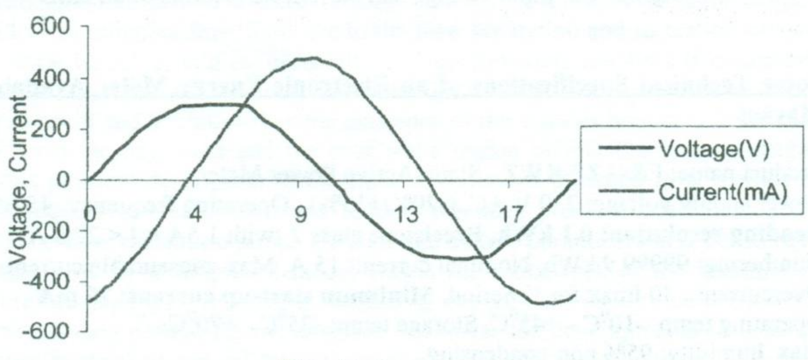

Figure A.3. Input voltage and current waveforms of an induction motor load

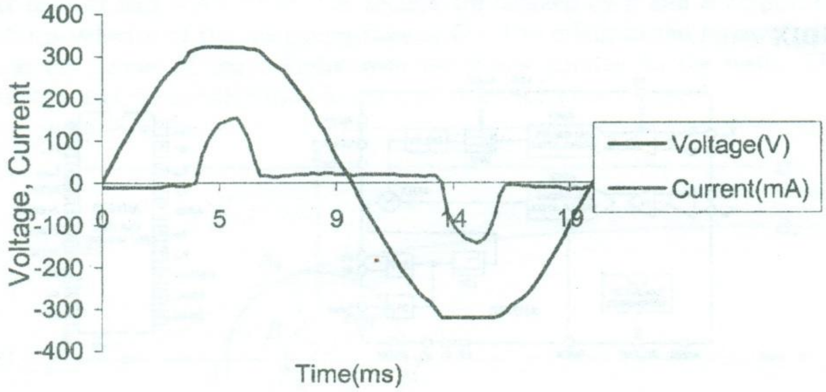

Figure A.4. Input voltage and current waveforms of a computer load

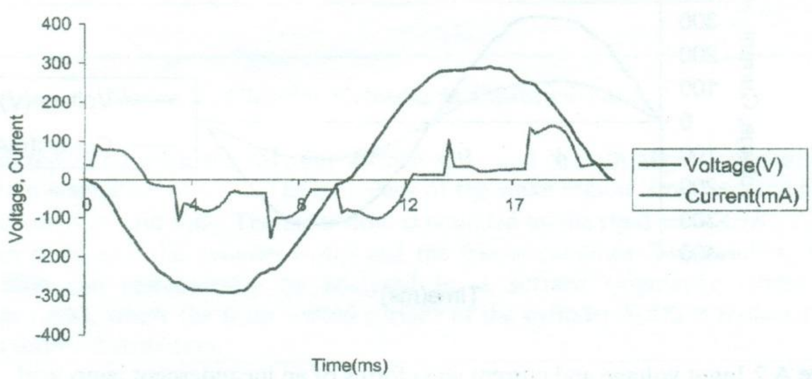

Figure A.5. Input voltage and current waveforms of an ASD

Some Technical Specifications of an Electronic Energy Meter Available in the Market

Product name: F&G Z7-KWZ Static Active Power Meter
Power supply voltage: 230 V AC, (-20%/+15%) , Operating frequency: 45/65 Hz
Reading resolution: 0.1 kWh, Precision: class 2 (with 1.5A < I < 22.5 A)
Numbering: 99999.9 kWh, Nominal current: 15 A, Max. measurable current: 22.5 A
Overcurrent : 30 Imax for ½ period, **Minimum start-up current: 75 mA**
Operating temp: -10^0C - $+45^0C$, Storage temp: -25^0C - $+70^0C$
Max. humidity: 95% non-condensing,
Output pulse voltage: -2.5 V +2.5V respect to neutral, pulse current: 1 mA max.
Output pulse duration: 75 msec approx.