Transients and Electric Metering

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Abstract

The electricity market deregulation or in other words, the need of increased efficiency and customer demands has lead to introduction of automatic reading systems. According to this, there have been thoughts that different kinds of disturbances can possibly cause problems with distance readings of electricity meters.

The purpose of this master thesis has been to investigate transients influence on electricity meters and automatic meter reading systems in general and also check if there is a reason to suspect that certain transients can cause reading faults (missing readings or faulty readings), in particular.

Mainly, the thesis is dealing with PLC technique based systems but also other types of communications techniques are studied. The thesis also includes getting deeper knowledge about the legislation regulating decisions about introduction of AMR systems in Sweden. Contact with manufacturers of electricity meters and AMR systems has been taken for borrowing necessary equipment.

A number of setup configurations have been tested and the transients have been measured in laboratory environment. The aim was to investigate if AMR systems and electricity meters are reliable and properly working with influence from switching transient disturbances.

The results from the measurements show that it is not likely that switching transients can cause any change in the readings from electricity meters or value changes in the meter itself, but they have the ability to sometimes block the communication so that the values are not transferred. This can be an important fact depending on how often and how many times the transmission is sent.

Keywords: Transients, electricity meters, AMR systems, PLC communication …

Abbreviations

AMR	Automatic Meter Reading
CENELEC	European Committee for Electrotechnical Standardization
DCU	Data Concentrator Unit
EFT	Electrical Fast Transient
EUT	Equipment Under Test
GRP	Ground Reference Plane
HCS	Host Central Station
IEC	International Electro technical Commission
MIU	Meter Interface Unit
MMIU	Multi-channel Meter Interface Units
PSTN	Public Switched Telephone Network
PLM	Power Line Modem
PLC	Energy meter reading through power line communication channel
kWh	kilowatt-hour

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Introduction

1.1 Background

The energy consumption in Sweden is forecasted by the distribution companies based on habits and consumption during the previous years. To get a result closer to the actual consumption the Swedish parliament has approved a new energy law that states that every energy meter must be read at least once a month by 1 July 2009. Since this is untested there is no standard set for the communication techniques. Therefore, to achieve this aim several companies have constructed different systems that can remotely read energy meters. These systems communicate with the meters by several different mediums such as power lines, telephone cables, radio and fibre optics.

Since some of these techniques are relatively new and untested in large scales there is an uncertainty if they can cope with disturbances. What will happen if transients occur at the same information channel that the values from the meters are transferred on?

1.2 Aim

- Literature study of transients and energy metering
- Study how energy meters is affected by different types of transients
- Study how communication over the electric net works in the presence of transients
- Find out the risks with remote reading of energy meters. Are there problems with security or reliability?

1.3 How the aim has been achieved

- Theoretical analysis of different transient amplitudes and frequency.
- Numerical modeling of different experimental setups to make sure the equipment can handle the voltage and current transient
- Experiments with creating different kinds of transients to try and disturb the meter and/or the communication.

1.4 Structure of the thesis

Chapter 2: Transients describes the general principles of transients.
Chapter 3: IEC 804-1 standard describes the standard in question.
Chapter 4: Remote reading describes some of the more common techniques developed for remote reading of energy meters.
Chapter 5: Legislation describes the current laws concerning remote reading of energy meters and the background to why the new law was developed.
Chapter 6: Calculation describes some of the calculation that are used as a comparison to the measured values
Chapter 7: Measurements and results describe the experimental part of the thesis.

Theory

2. Transients

2.1 General

Electromagnetic transients are abrupt changes of the voltage or the current waveform. They occur when the network changes from one steady state into another. Unfortunately, this definition is so general that it can be used to describe almost any disturbance that occurs in the power system. Therefore, this definition can be extended by adding that transients are shorter than voltage sags, with duration of 0.5 cycles up to several seconds, or voltage swells and not periodic within each cycle like voltage notches [4, 5, 6].

Transients can be classified into two categories: impulsive (unidirectional) and oscillatory.
Rise times can range from nanoseconds to milliseconds and amplitudes of low voltage transients are generally below 6 kV because of settings of over voltage protection (the highest over voltage which should not trip the protection should not cause any damage on the equipment). The IEEE Standard 1159:1995 gives the following classification for transients [3]:

Categories	Typical spectral content	Typical duration	Typical voltage magnitude
Impulsive transients			
Nanoseconds	5 ns rise	< 50 ns	
Microseconds	1 μs rise	50 ns - 1 ms	
Milliseconds	0.1 ms rise	>1 ms	
Oscillatory transients			
Low frequency	< 5 kHz	0.3-50 ms	0-4 p.u.
Medium frequency	5-500 kHz	20 μs	0-8 p.u.
High frequency	0.5-5 MHz	5 μs	0-4 p.u.

***Table 1**. Characteristics of transients according to IEEE 1159:1995*

An impulsive transient is a sudden change in the steady-state condition of the voltage, the current or both, which is unidirectional in polarity (either positive or negative). It can be characterized by rise and decay time, amplitude and total duration time. Impulsive transients are mostly caused by lightning and they are normally not conducted far from the place where they enter the power system. In some cases, impulsive transients can excite the natural frequency of power system and produce oscillatory transients.

Oscillatory transient oscillates with some predominant frequency changing its polarity rapidly. It can be described by its spectral content, duration and amplitude. Oscillatory transients are caused mostly by capacitor switching in the power system.

Transients in an electrical system can be generated by lighting, switching, resonance and faults [3, 4, 5].

Lightning transients occur when lightning strikes a conductive point which can result in discharge of huge currents. Developed voltage is the discharge current multiplied by impedance of the system as seen by the current. Lightning transients are a random and rare but severe and damaging phenomenon (it is the greatest single cause of line outages).

Switching transients are generated when interrupting the current in the circuit. The inductance in the circuit opposes a change in the current by inducing a voltage and therefore the current can not be broken instantly. The faster the interruption the higher the voltage. Power circuits are always inductive and a high induced voltage will occur across contacts of a circuit breaker with normal operation. Switching transients can be generated by load switching, capacitor switching, inductor switching, current chopping, operation of power electronics devices (FACTS devices), transformer energizing etc. They are almost always oscillatory and can be controlled by proper design of the switch and a proper switching point when the natural current is zero.

During fault conditions large currents can be generated in an electrical system. These over-currents are interrupted by fuses or breakers. Interruption of fault current can generate over-voltage impulse and the magnitude of this voltage depends on the value of the fault current and the interruption speed. The generated voltage impulse can interact with the capacitance and the inductance of the electrical system and produce oscillations at frequencies much higher than the fundamental frequency of the power system. The voltage magnitude can exceed two times the peak value of the voltage.

The linear resonance is the phenomenon behind the magnification of harmonics in power systems. Power system circuits contain both inductances and capacitances and have one or more natural frequencies. When a power system produces these frequency harmonics (certain loads or a particular type of equipment), a resonance may develop and at that frequency the voltage and the current can reach high values. Two kinds of resonances are common, a parallel and a series resonance [8]. A parallel resonance occurs when the reactance of the shunt capacitance and the inductance of the distribution system cancel each other. A series resonance occurs when the shunt capacitor and the transformer or the distribution line inductance appear as a series LC circuit to a source of a harmonic currents [8].

2.2 Transmission of electromagnetic transients

Electromagnetic transients can be transmitted from the source by [6]:

- Conduction
- Induction
- Radiation

Conduction is the most common way of transient transmission and conducted transients also cause the most severe damages in the power system. These transients can be conducted via the in-feed line or via the ground. If they penetrate through the grounding system they can raise the potential at different grounding points and thereby contribute to the rise of the voltage of the system components.

Transmission by induction can occur by magnetic or electrostatic coupling. The magnetic coupling can be reduced by minimizing the area over which the magnetic flux is linked, by installing the lines close to each other, by increasing the separation distance between circuits or by magnetic shielding. Electrostatic coupling can be reduced by increasing the separating distance between the noise source and the system or by shielding.
The electromagnetic fields induce voltages on an object and the magnitude depends on the orientation, the size and the shape of the object and the strength of the source of radiation. It is not unusual that a lighting stroke induces a voltage high enough to damage the equipment. Switching transients in substation can cause damage of relays located in the neighbourhood.

2.3 Effects of transients

Effects of transients on neighbouring equipment are different and they depend on the magnitude, the duration, the rate of voltage rise, the energy and the number of transients. The main problems transients cause are damages of different components and mal-operation of the equipment. These problems are well known and deeply explored. Examples of such events are [3]:

- tripping of adjustable speed drives or other loads
- damage of transistor, thyristor or diodes
- insulation failures (breakdown or sparkover)
- fuse blowing
- damaged TV, computer, VCR or printer
- switch failure
- protection device tripping and failure

Other problems that transients can cause are data processing equipment mal-functions or upsets of different kinds. Examples of these can be:

- bit rate errors
- memory error, resets or lockups
- charging of stray capacitances on P.C. boards which can change logical signals

These effects of transients are not so widely spread or investigated.

3 IEC 804-1 standard

A technical progress of electronic systems becomes possible by developing fast logic devices operating at low levels of voltage and power. This can make these advanced circuits sensitive to external interfering disturbances resulting in hardware failures or system upsets like bit errors, resets, memory errors or lockup. To be protected from such effects the equipment must be tested by realistic tests.

The International Electro technical Commission (IEC) has created a document IEC 801-4 that characterizes setup and procedure for conducting electrical fast transient (EFT) immunity tests. The purpose of the test is to check equipment immunity to fast transients resulting from switching.

EFT involves a burst of fast pulses which are associated with switching phenomena originated from devices like relays, fluorescent lights or air contactors when interrupting inductive or capacitive loads.

The document specifies characteristics of the burst generator (even called EFT generator or transient generator), effects on circuits, coupling/decoupling methods, test severity levels and equipment setup.

According to the document, every single EFT pulse is a unidirectional pulse with a rise time of 5 ns and pulse duration of 50 ns (see figure 1).

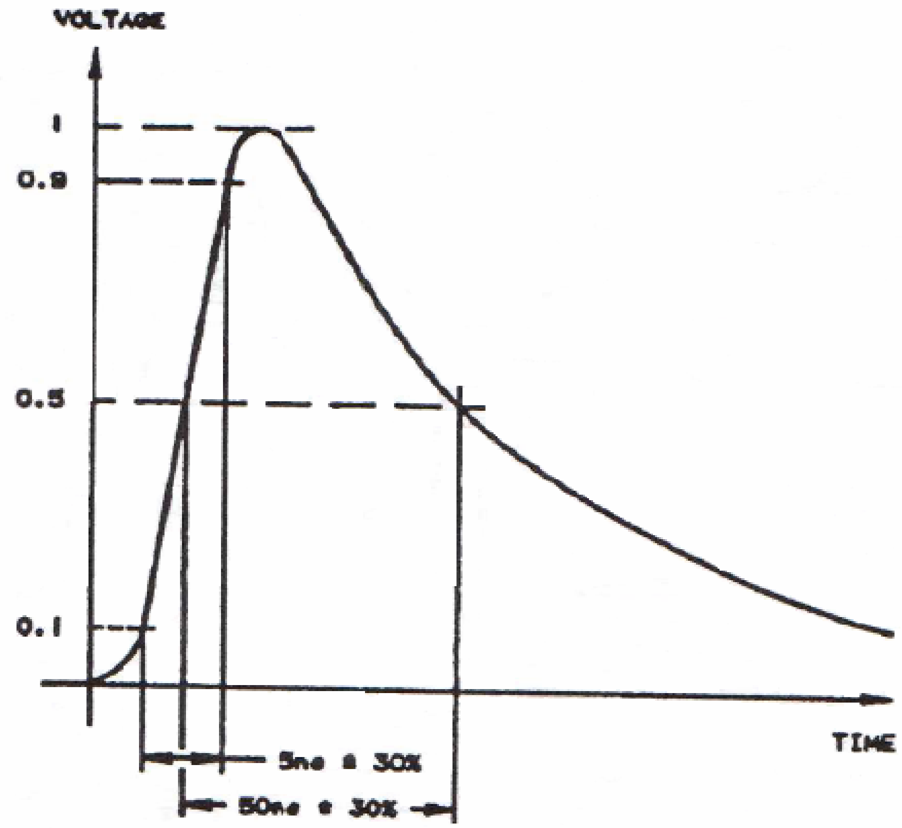

Figure 1. *Single EFT pulse*

EFT burst is specified as a sequence of EFT pulses with 15 ms burst duration. Pulse repetition rate within the burst is a function of severity level. Finally, the burst is repeated with a period of 300 ms (see figure 2).

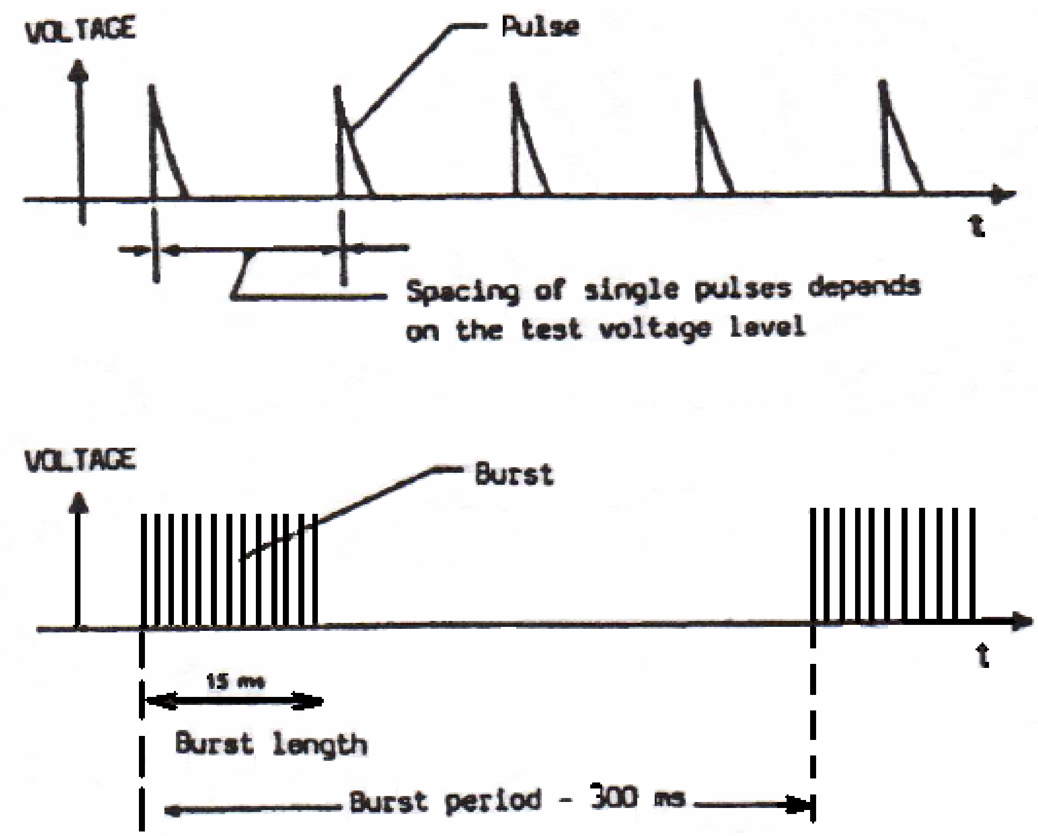

Figure 2. *EFT burst sequence*

Specified severity levels, that are used to define environmental conditions that can be expected for the use of the equipment, are shown in table 2.

Severity Level	Peak Voltage	Pulse Repetition Rate	Comment
1	0.5 kV	5 kHz	Well-protected environment: Good separation of power supply lines from control lines, cables shielded and grounded
2	1 kV	5 kHz	Protected environment: Unshielded power and control lines but physically separated from signal and communication lines
3	2 kV	5 kHz	Typical industrial environment: Poor separation between power supply and signal and communication lines
4	4 kV	2.5 kHz	Severe industrial environment: Does not have any separation between power supply and signal lines
5	Special	Special	Special considerations: Intended for equipment requiring a higher or a lower severity level, specified by the parties involved

Table 2. *Test severity levels*

The IEC 801-4 document prescribes the coupling of the transient generator output to the Equipment Under Test (EUT) in two ways: a direct coupling and a coupling by a capacitive coupling clamp. The direct coupling method (see figure 3) uses a discrete capacitor (capacitance 33 nF) for terminating EFT generator to the EUT. This method is intended for testing ac/dc powered equipment which involves low impedance circuits as in the performed test.

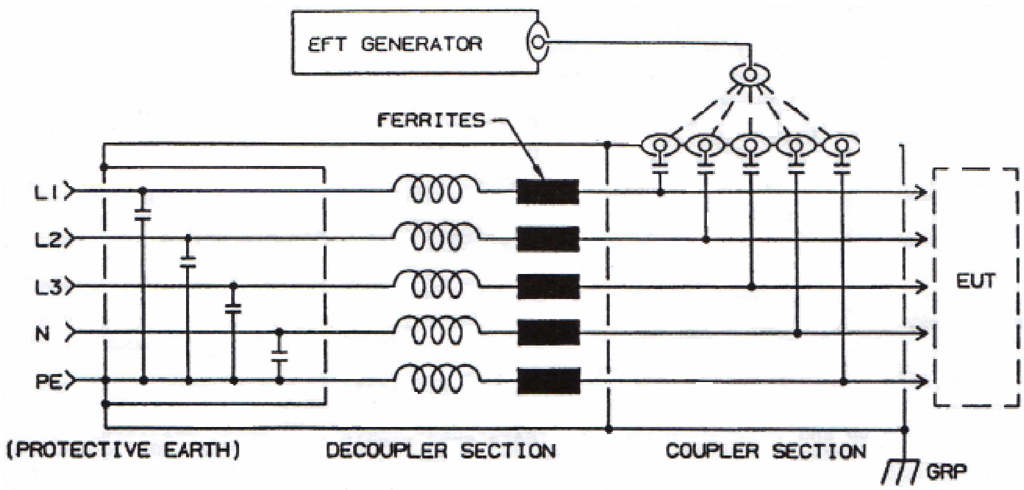

Figure 3. *Decoupler, coupler, EUT and EFT generator*

The capacitive clamp method is used when testing high impedance circuits, usually data signals and control lines.
EFT pulses must be attenuated before they reach the equipment (that is not being tested) upstream from the EUT. This is done by a decoupler. The puls attenuation must be higher then 20 dB. The IEC 801-4 document specifies also that the test area should be covered with copper or aluminium, with a minimum thickness of 0.25 mm. This metal surface is referred as a Ground Reference Plane (GRP) and its minimum dimensions should be 1m x 1m and depend on dimensions of the EUT. It must extend beyond the EUT by more then 0.1 m on all sides. GRP must be bonded to the protective earth. GRP has tens to hundreds of picofarads almost inductance-free capacitance to free space and that means very low impedance for the 5 ns rise time EFT [4].That is why the GRP is a very important component in the system setup.

4. Remote Reading

The system of remote reading (figure 4) of the energy meters consists of a transmitter at the meter, a collector and a main receiver. The data is sent from the meters to the collector, which is placed at a substation. If there is great distance between the meter and the collector a repeater may have to be used to amplify the signal. The collector collects data from several meters and sends it on to the main receiver which stores the values from the different customers on a computer.

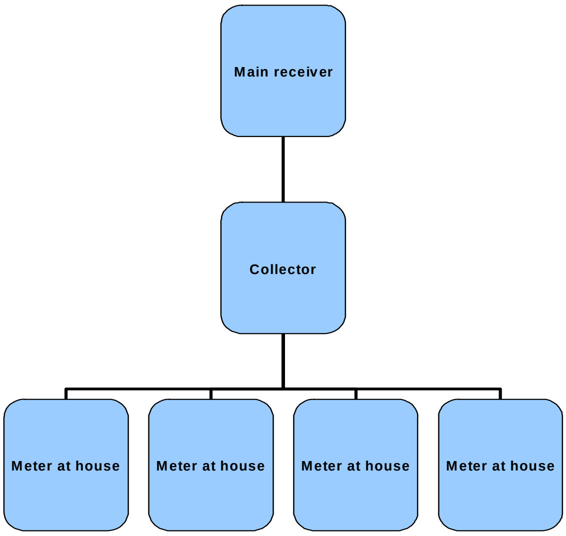

Figure 4*: System of remote reading*

Regarding communication between the meters and the collector there is a number of different technologies, for instance PLC (power line communication), radio and GSM. These different techniques can also be combined for instance by having PLC at the outer part of the system then transform the signal to radio at another part and then to data communication to the main system. The more common techniques are described in the following subchapters [9, 10].

4.1 PLC (Power Line Communication)

With the PLC technique the existing power lines that already are connected to the meters are used as the signal media and therefore no expensive upgrades of the communication network are required. In Europe, power line signalling must be confined to the 9-148.5 kHz frequency range. This spectrum is further divided into bands and allocated for specific applications as follows:

- A-band 9-95 kHz for electricity suppliers
- B-band 95-125 kHz for consumer use without protocols
- C-band 125-140 kHz for consumer use with CENELEC protocol
- D-band 140-148.5 for consumer use without protocols

Since the power lines are owned by the power companies, no cost will be charged for the use of the power lines. The communication in power lines is possible due to the fact that the communication is placed in the high frequency range while the energy transmission is in the 50 Hz range. Hence it is possible to get energy components of the signal by applying a low-pass filter to it, and the communication part of the signal by applying a high-pass filter. The downside of this technique is that the power lines are not made for communication and therefore transmits radio waves that can disturb other equipment and transmissions.

4.2 Radio communication

To enable radio communication a radio modem which transforms the data to radio waves with a certain frequency and bandwidth is used at the meter. The radio signal is then filtered and adapted so that it can be sent over the radio channel. Modulation of the signal to the correct carrier frequency is performed by the modem and then it transmits the signal as an analogue signal to the collector. The transmission takes place in the UHF-band at about 400 MHz. When the signal reaches the collector it transforms it back into a data signal and sends it on to the main system. A problem with this technique could be that the weather conditions affect the radio transmission, and then the signal quality fluctuates.

4.3 Fibre optics

Communication by fibre optics do not require any change of the signal, since it is already in digital form, and can therefore be sent straight to the main system. Fibre optics is really fast but requires great installation costs since the fibre optics must be placed underground and go all the way to every meter that will be a part of the communication. This could be a good alternative in the cities where almost every household have internet connection via fibre cable, but hardly in the more isolated areas of the country.

4.4 GSM (Global System for Mobile communication)

Use of the mobile net to send data from the meters to the main system is another option that does not require a new network, although it often requires some sort of antenna at the meter. Instead it is the cost of every single transmission that is the problem here. More communication cost more money so the more continuous the supervision is the higher the expenses get. There could also be problems with the communication when there is a lot of action on the net, for example at the big holidays. A positive thing is that the mobile net covers almost all of the country, including isolated households to which it would be expensive to create a communication line.

4.5 Signal wire

This signal wires are owned by the power companies, but are not a top priority. The wires are often badly maintained and only go to big customers, but have a good enough performance to work with remote control. This technique is rarely used.

4.6 Telephone net

The telephone net is owned by Telia and the power companies have to rent the line from them. Since there is no other option with this technique it means that Telia can dictate the terms of the rent which can make it expensive. The net is already in place, all that needs to be done is to install a modem at the meter and then draw a line between the modem and a telephone plug.

4.7 Satellite

This is the most advanced communication technique and it also requires the most advanced installation at the meter. Just like some of the other techniques the power companies have to rent the communication space, this time from private owners. Satellite communication will likely just be used on places where none of the other techniques will work.

4.8 Protocols

The most common protocols are LonWorks, which is an industrial standard, and M-bus, which is a bus protocol that is common in remote heating. In this report a system called TriDelta is used. Since all systems are under development now, the companies are reluctant to give out to much information about how the protocols work. Therefore it is hard to see what can go wrong in the different systems.

5. Legislation

Since the deregulation of the Swedish electrical market, a number of companies handling electrical distribution have been started. Although differing in prices and other details all companies handles the payment of the electricity in the same way. The prices the costumers have to pay are based on an assumption of how much they should consume (preliminary charging), based on what they have consumed the previous year. The difference between the estimated value and the actual consumption are then evened out when the meter is read once a year. On 11 of February 1999 an investigation group got the task to investigate among other things if the period of time between the measurements needed to be regulated and if the electricity bill should be based on actual consumption [11]. In the report these three advantages were suggested by using more frequent measurements:

1. The quality in the conventional calculation (schablonberäkning) could be improved.
2. The costumer would only pay for the actual consumption on every bill.
3. More focus on the electrical consumption could make the costumers more inclined to save energy.

The investigation did not find enough reason to recommend a removal of the preliminary charging though, since it was hard to estimate the benefits and costs. Thus the distribution companies were already busy with the introduction of and adaptation to the conventional charging reform. Based on the report the Swedish government decided that it was possible to introduce more frequent readings and to lower the limit for time based measurement. Since the new systems needed to make this happen are expensive when installed for many costumers, the government wanted to make this a long term solution. After all, the cost of new investments forced by new laws will in the end affect the costumers.

The governments judgement were that the distribution companies should have to read the energy meters and report the measured values for all customers at least once a month. The demand of monthly measurement, reading and reporting for all costumers should be obligatory by 1 of July 2009.

The department of energy agreed with the governments’ judgement but suggested that the demands should be introduced in two stages. The first stage should involve costumers that consume more than 8000 kWh/year and should be completed 1 of July 2006 and the second should involve all other costumers and be finished 1 of July 2009.

The Swedish parliament was positive to the government’s plan, with the changes made by the department of energy, to introduce monthly reading for all electricity customers 1 July 2009.

6. Calculations

Calculations in this work are based on the following assumptions:

- Voltage sources are infinitely strong, which means that source impedances are zero
- Low-pass filter capacitances are short-circuited by the voltage source and the serial inductances in the filter compared to the inductances in the setup circuit are so low that they can be neglected
- The impedance of electricity meter is so low (less then 0.1 Ω) that it can be neglected
- All effects of propagating electromagnetic waves caused by reflection from the transformer behind the source on transient recovery voltage are neglected
- Kirchhoff's law and lumped circuit elements are possible to use in modelling of the power system

6.1 Calculations of expected energy consumption

These calculations are valid for the circuit configuration shown in figure 5 but the calculations are similar also in other used configurations. Matlab files dealing with this are found in appendix D.

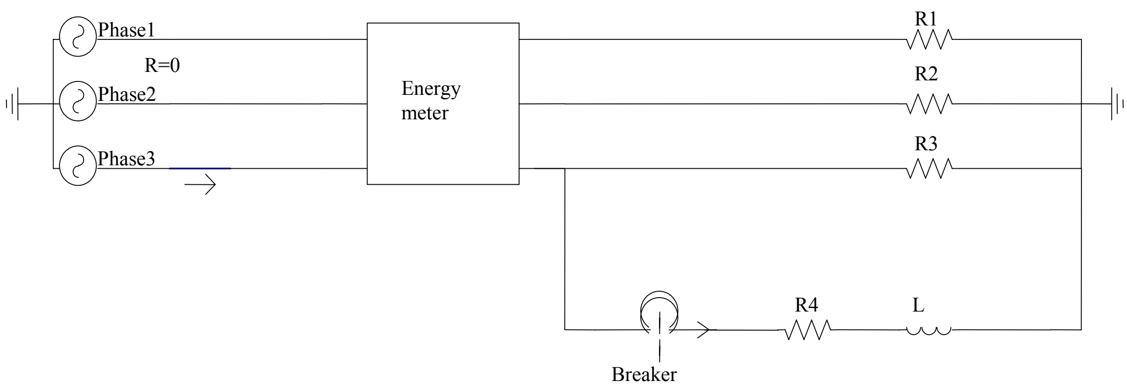

Figure 5. *Circuit configuration*

The used energy meter is equipped with a S0 pulse output which means the meter will send 500 square pulses for every kWh of consumed energy. These pulses have duration of 40 ms and they are referred to as ordinary meter pulses. When the breaker (the contactor) is pressed or released a transient voltage spike appears on the S0 output. The schematic look of the measured output voltage is shown in figure 6.

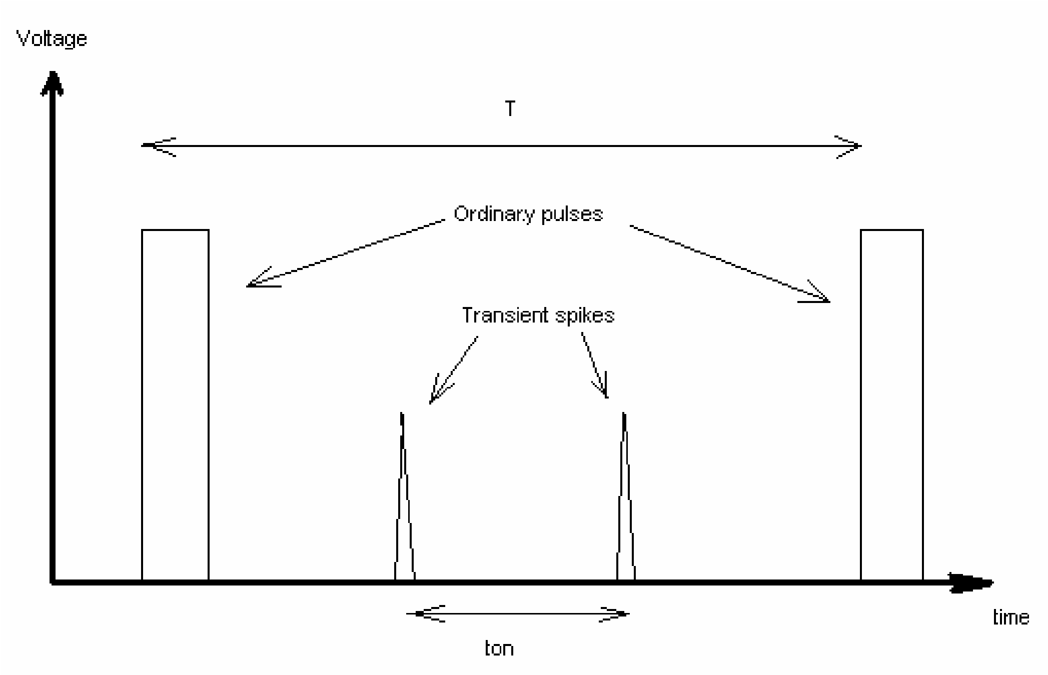

Figure 6. *Calculation of expected pulse duration*

The symbol definitions are as follows:

U is the phase voltage of the source
P_{R1}, $P_{R2,}$ P_{R1R2L} are the active powers in R1, R2 and in the entire third phase respectively
cos φ is the power angle of entire third phase
$\left|Z_{phase3}\right|$ is the absolute value of the impedance in the third phase
t_{on} is the time that the parallel circuit in the third phase is on
t_{off} is the time that the parallel circuit in the third phase is off
T is the time period of the ordinary S0 pulses
E_{on} is the total consumed energy while the parallel circuit in the third phase is on
E_{off} is the total consumed energy while the parallel circuit in the third phase is off
MC is the meter constant, 500 pulses per kWh telling which states that the S0 output will give 500 pulses if the energy consumption is 1 kWh, or in other words, the constant is 2 Wh/impulse

Active power before the switch on is:

$P_{off} = (U^2/R3) + (U^2/R1) \cdot 2$ since R1=R2 (1)

Active power after the switch on is:

$P_{on} = P_{R1} + P_{R2} + P_{R1R2L}$ (2)

$P_{R1R2L} = \frac{U^2}{\left| Z_{phase3} \right|} \cdot \cos \varphi$ (3)

The sum of E_{on} and E_{off} should be the same as the value of 1 impulse and also the sum of t_{on} and t_{off} should be equal to T:

➔ $E_{on} + E_{off} = MC \cdot 3600$ [Ws] $= P_{on} \cdot t_{on} + P_{off} \cdot t_{off}$ (4)

and $T = t_{on} + t_{off}$ (5)

(4) and (5) give us

$$T = t_{on} + \left(\frac{7200 - P_{on} \cdot t_{on}}{P_{off}} \right) = t_{on} \cdot \left(1 - \frac{P_{on}}{P_{off}} \right) + \frac{7200}{P_{off}} \quad (6)$$

6.2 Calculations of the expected transient recovery voltage

These calculations are valid for the circuit configuration shown in figure 7 but the calculations are similar also in other used configurations. When the contacts of the breaker (the contactor) are trying to interrupt the current an arc is formed between the breakers poles. At current zero the arc is quenched and the transient recovery voltage starts to appear across the open contacts.

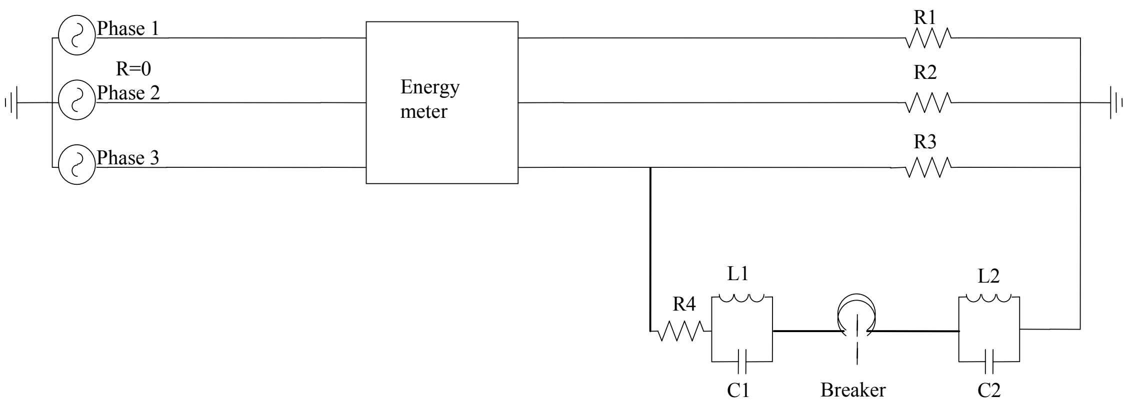

Figure 7. *Calculation of transient recovery voltage*

This voltage named V_{tr} is given by:

$V_{tr} = Z*i$

Z = The impedance of the network seen from the open contacts of the breaker
i = The injected current between the contacts.

According to the Thevenin principle the third phase can be modelled as an equivalent circuit shown in figure 8.

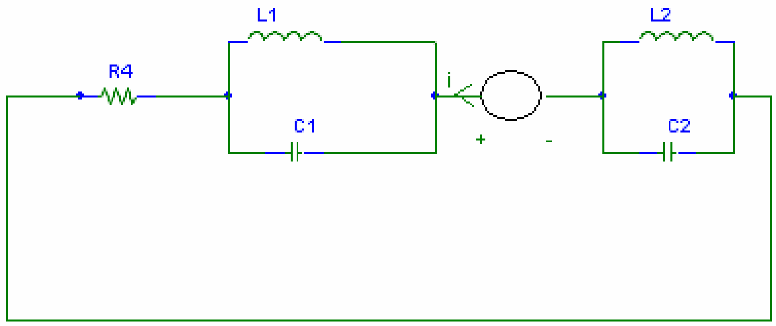

***Figure 8** Equivalent circuit*

The circuit expressed with Laplace transforms and with the following definitions:

$$\omega_1 = \frac{1}{\sqrt{L_1 \cdot C_1}} \qquad \omega_2 = \frac{1}{\sqrt{L_2 \cdot C_2}} \qquad \omega = 2 \cdot \pi \cdot 50$$

$$Z_1 = \frac{s}{C_1(s^2+\omega_1^2)} + R4 \qquad Z_2 = \frac{s}{C_2(s^2+\omega_2^2)}$$

Assuming that the current through R4 before opening the breaker is $I = I_0 \cdot \sin(\omega t)$, then the injected current through the breaker is $i = - I_0 \cdot \sin(\omega t)$.

The transient voltage, V_{tr}, in the frequency domain is:

$$V_{tr}(s) = \frac{-I_0 \cdot \omega}{s^2+\omega^2}[Z_1+Z_2] = \frac{-I_0 \cdot \omega}{s^2+\omega^2}\left[\frac{s}{C_1(s^2+\omega_1^2)} + R2 + \frac{s}{C_2(s^2+\omega_1^2)}\right]$$

Transforming the transient voltage back to time domain gives the following result:

$$V_{tr}(t) = -I_0 \cdot \omega \cdot \left[\frac{\cos\omega - \cos(\omega_1 t)}{C_1(\omega_1^2-\omega^2)} + \frac{\cos\omega - \cos(\omega_2 t)}{C_2(\omega_2^2-\omega^2)}\right] - I_0 \cdot R2 \cdot \sin(\omega t)$$

The plot of this function is used to control magnitude and frequency of the created transients before making any physical connections.

Measurements and Results

7. Measurements on an ordinary energy meter

The first measurements were made on an ordinary energy meter (appendix B) to see if the transients had any effect on the meter before testing the communication. To investigate some different cases with varying transients the components (appendix A) in the measure circuit were changed to generate a variation of transients. The parameters used in the setups were R1=49.6 Ω, R2=496 Ω, R3=96.2 Ω, R4= 70.6 Ω and L=0.04 Henry. The measurements made on the energy meter were done on the S0 output, where the communication module would have been plugged in if present. All setups were controlled for steady-state currents and also expected transient recovery voltage was calculated in accordance to section **6.2** before making any physical connections. These different setups were also used in the second measurement when checking the communication of a complete AMR system (appendix C).

7.1 Transients with high amplitude

The transients that appear in these setups are in the same frequency range as the net since there is no frequency altering couplings in the line that most of the current passes through. In this category there are two different setups; one with an inductance (figure 9) and one with a capacitance (figure 10). The purpose of these couplings is to see if the energy meter is affected by high currents and/or voltages even though they are not in the frequency range of the transmission. The resistance R is varied between 49.3 and 80.1 Ω.

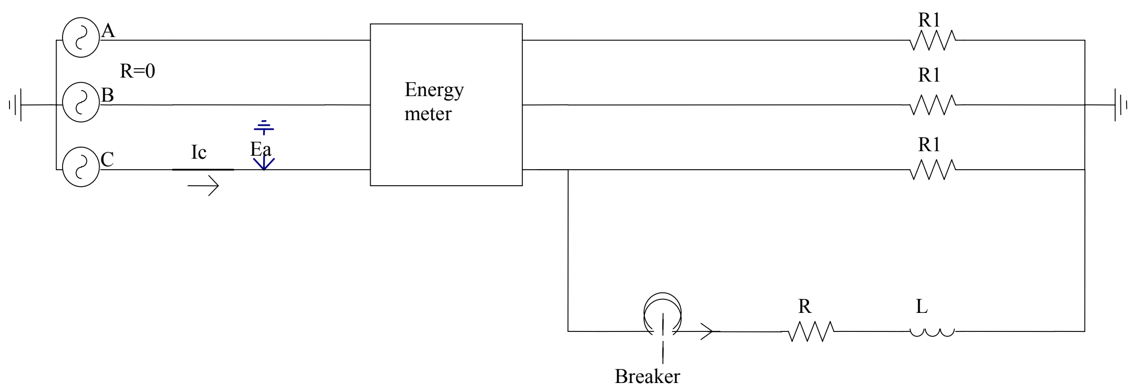

Figure 9. *Coupling where the parallel branch consists of an inductance and a resistance in series*

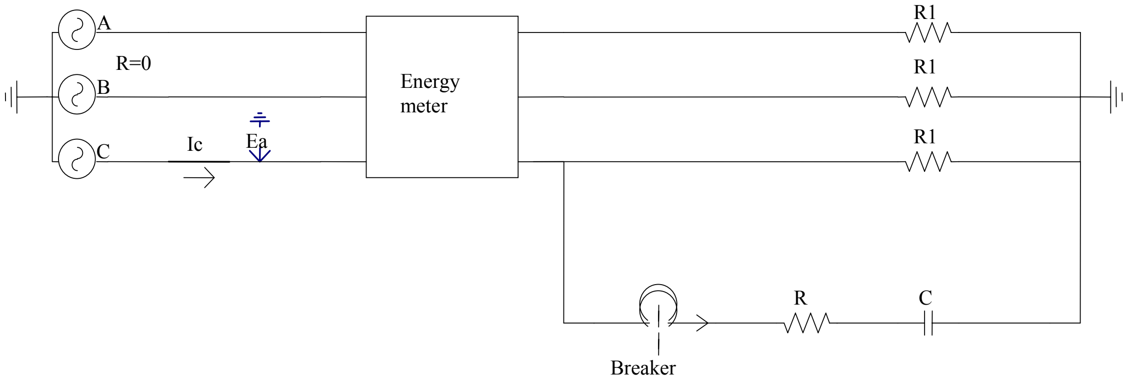

Figure 10. *Coupling where the parallel branch consists of a capacitance and a resistance in series*

When measuring on the S0 output during the time that the breaker was closed or opened there were clear signs that the transients created by these operations (figures 11 & 12) were propagated to the output (figure 13).

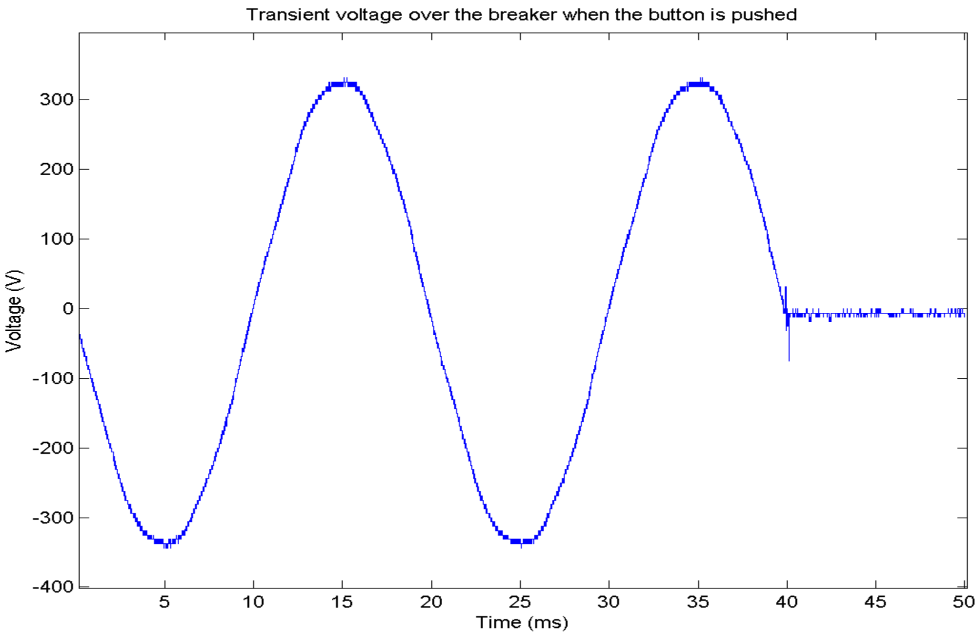

Figure 11. *Transient that occurs at the breaker when the parallel branch is switched in.*

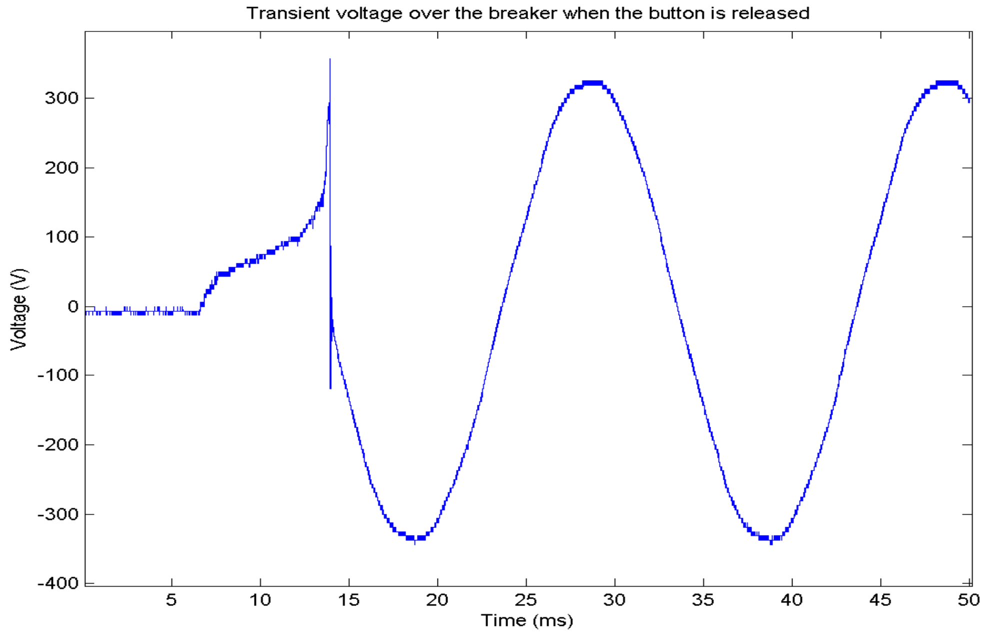

Figure 12. *Transient that occurs at the breaker when the parallel branch is switched out.*

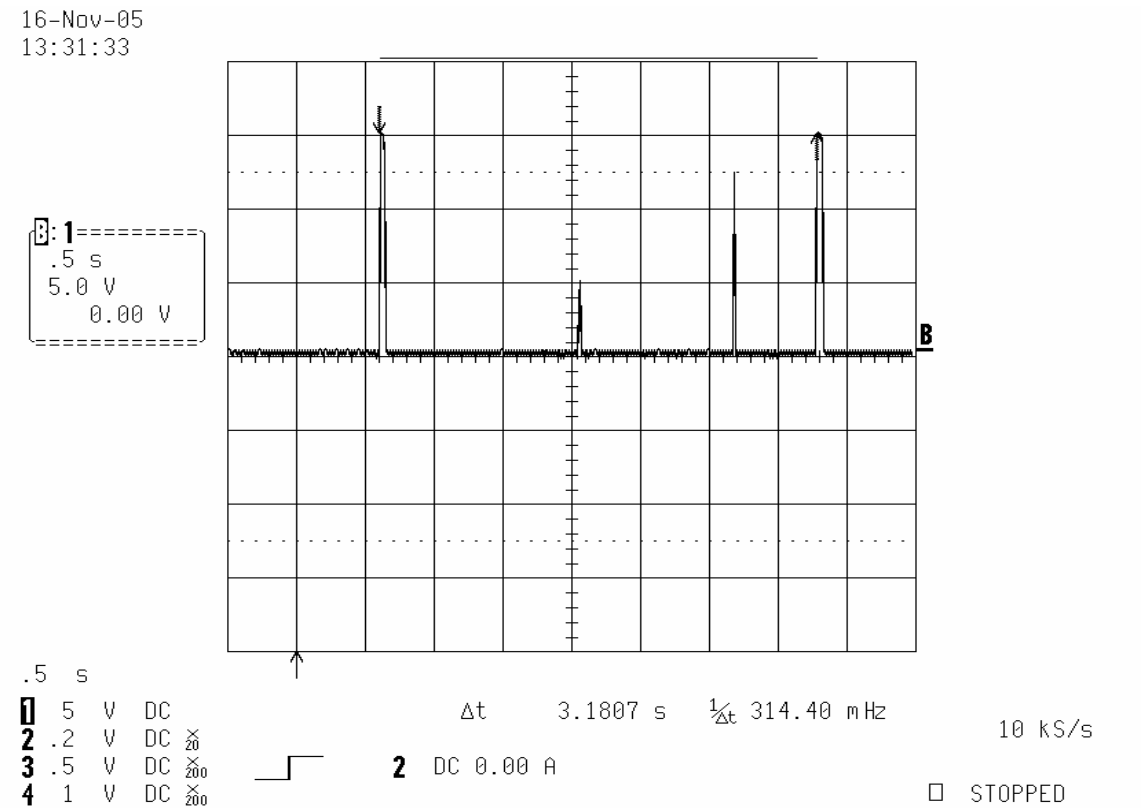

Figure 13. *Transients propagated to the S0 output*

Although in these pictures there seem to be a connection between the amplitude of the transient and the amplitude at the S0 output, further test showed that the amplitude of the pulses were completely random. There was no noticeable difference in the frequency or amplitude of the pulses that were propagated to the S0 output whether the parallel branch consisted of amplitude altering or frequency altering couplings.

7.1.1 Measurements on the S0 output

To get a reading from the S0 output a separate coupling was made between the S0 output, the oscilloscope and a power source, all in series. There were no visible effects on the energy meter when looking on the display. The measurements on the S0 output to see if the transients caused any problems for the meter when measuring the used energy can be seen in tables 3-7. The highest difference (in table 3) of the values is 9.8 % and it is lower than the uncertainty of the calculated value (21.8 % in appendix A), which means that the created transients probably have no effect on the frequency that the pulses are transmitted at.

t_{on} [ms]	1156.8	1060.6	1128.9	935.1	728.9
Tcalculated [s]	2.8906	2.905	2.898	2.93	2.963
Treal [s]	3.1213	3.0522	3.1807	3.0351	3.1102
Difference in [s]	0.231	0.1473	0.283	0.105	0.147
Difference in [%]	8	5.1	9.8	3.6	5

Table 3. *Results of the measurements on the S0 output when using the setup in figure 9*

t_{on} [ms]	1165.5	1091.6	890.8	1012	1513.5	1047.5	1058.8	926.4	1216	1113.4
Tcalculated [s]	2.0492	2.0616	2.0955	2.0751	1.9905	2.0691	2.0672	2.0895	2.0407	2.058
Treal [s]	2.1844	2.1863	2.1883	2.1813	2.1662	2.1822	2.2063	2.2043	2.2164	2.1803
Difference in [s]	0.1352	0.1247	0.0928	0.1062	0.1757	0.1131	0.1391	0.1148	0.1757	0.1223
Difference in %	6.2	5.7	4.2	4.9	8.1	5.2	6.3	5.2	7.9	5.6

Table 4. *Results of the measurements on the S0 output when using the setup in figure 17 when L=0.04 H and C=5.9nF*

t_{on} [ms]	1038.4	1241.4	538.4	1027.4	944.9	772	939.9	1026.3	990	1141.4
Tcalculated [s]	2.0706	2.0364	2.155	2.0725	2.155	2.073	2.0864	2.0727	2.0788	2.0532
Treal [s]	2.1744	2.1894	2.1984	2.1784	2.1914	2.2075	2.2003	2.1934	2.2104	2.1964
Difference in [s]	0.1038	0.1530	0.0435	0.1059	0.1050	0.092	0.1131	0.1207	0.1316	0.1432
Difference in [%]	5	7.5	2	5.1	5	4.3	5.4	5.8	6.3	7

Table 5. *Results of the measurements on the S0 output when using the setup in figure 17 when L=0.04 H and C=2.65nF*

t_{on} [ms]	761.1	999.1	1359.8	1242.6	1285.6	1198.3	1178.5	1049.1	1173.1	880.1
Tcalculated [s]	2.1174	2.0772	2.0164	2.0362	2.0289	2.0437	2.047	2.069	2.048	2.097
Treal [s]	2.1975	2.2034	2.1583	2.1623	2.2033	2.2024	2.2065	2.2133	2.1713	2.1953
Difference in [s]	0.0801	0.1262	0.1419	0.1261	0.1744	0.1587	0.1595	0.1443	0.1233	0.0983
Difference in %	3.6	5.7	6.6	5.8	7.9	7.2	7.2	6.5	5.7	4.5

Table 6. *Results of the measurements on the S0 output when using the setup in figure 17 when L=0.04 H and C=1.47nF*

t_{on} [ms]	652	553.2	650.7	548.1	477	667.8	1102.8	1576.2	1659.1	1034
Tcalculated [s]	2.1488	2.1635	2.149	2.1642	2.1748	2.1464	2.0818	2.0114	1.999	2.092
Treal [s]	2.1974	2.1973	2.1928	2.1874	2.2005	2.1812	2.2025	2.1763	2.1384	2.1673
Difference in [s]	0.0486	0.0338	0.0438	0.0232	0.0257	0.0348	0.1207	0.1649	0.1394	0.00753
Difference in [%]	2.3	1.6	2	1.1	1.2	1.6	5.8	8.2	7	3.6

Table 7. *Results of the measurements on the S0 output when using the setup in figure 19 when L=0.04 H, C1=1.47nF, C2=2.65nF and C3=5.9nF*

7.2 Transients with high frequency

Since there are capacitances and inductances in parallel in these couplings the resulting transient when these are energized will have a different frequency than the net frequency. The aim of this is to disturb the PLC systems transmission on the lowest frequency of the energy meter that is sent on the A-band. Since the AMR system used during normal operation use frequency in the D-band the communication had to be manually modified to the lowest frequency in the A-band (46 kHz). If it is possible to disturb that frequency, it is possible, but harder, to disturb all the frequencies that the transmission takes place on. Something to take into consideration in these cases is that the smaller the component values, thus higher frequency, the smaller the transient amplitudes.

7.2.1 Coupling with the burst generator

Measurements with the EFT generator involved are performed in accordance to IEC 804-1 standard. An aluminium GRP with dimensions 1.6m x 1m x 2.5mm is used and interfacing is accomplished by using a direct coupling method. The burst duration is varied from 0 to 15 ms continuously and the pulse frequency in steps of 1, 3, 5 and 10 kHz. The amplitude of the burst voltage is varied in steps of 0.5, 1, 2 and 4 kV and also the polarity of the voltage is changed.

The EFT generator can be connected to one, two or all three lines and also all three lines and the neutral line. The transients are applied to the lines through a coupling filter (low-pass) which also protects the power source and thereby the rest of the net from the transients generated. The same procedure is performed in both of the setups, the one with the energy meter only (figure 14) and the one with the whole AMR system (figure 15).

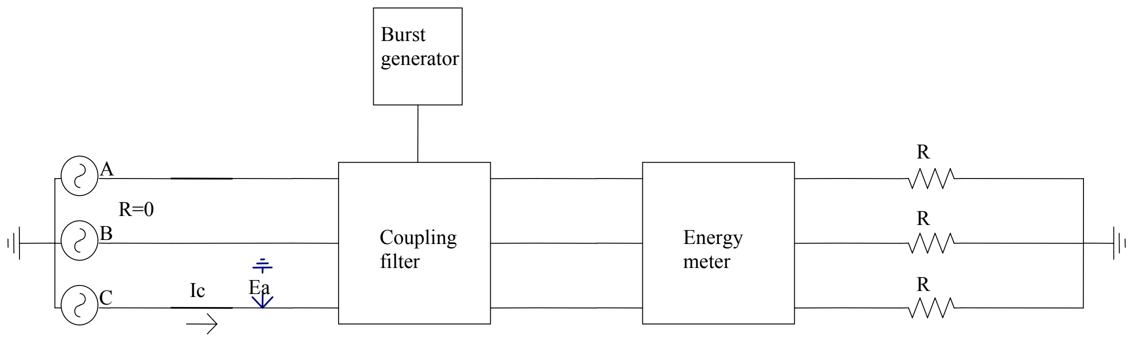

Figure 14. *Coupling with the burst generator*

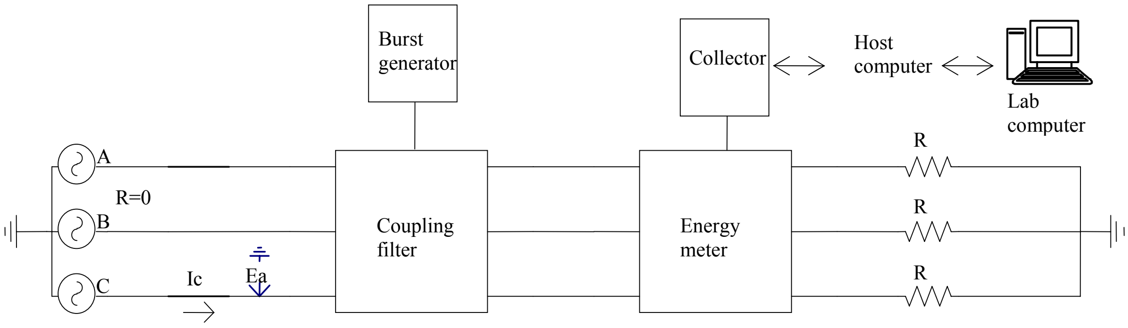

Figure 15. *Coupling with the burst generator (AMR system)*

To simplify the coupling schematics the collector and the communication equipment have been left out further on. The plots (figure 16) show how the burst generator disturbs the current at two different times and the S0 output of the ordinary energy meter.

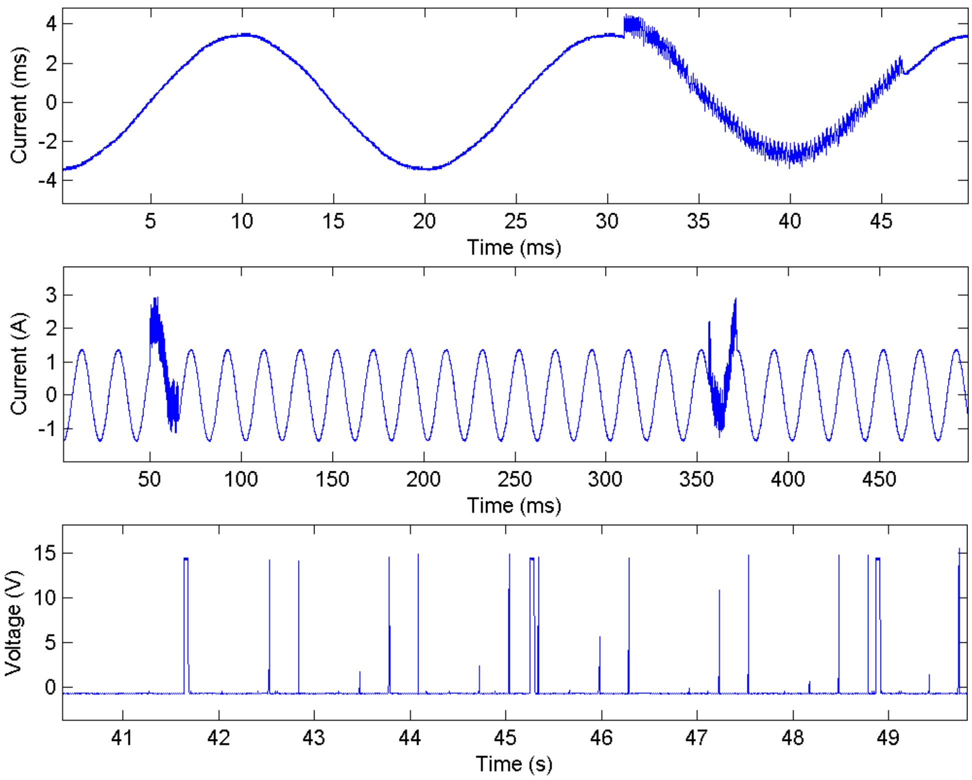

Figure 16. *Burst generator in parallel with resistance. The top plot shows one burst the middle one the time between two burst (300 ms) and the bottom one shows the S0 output when the burst generator is on.*

When using the burst generator as a transient source to disturb the complete AMR system it disturbed the communication to the degree that the information sent did not get through to the main system. It did however not manage to corrupt the data sent and neither did it manage to block all transmissions to the main system.

7.2.2 Couplings with a user made loads as parallel switched-in couplings

This coupling (figure 17) was used three times with varying capacitance C, to get different transient frequency. These values were 1.47 nF, 2.65 nF and 5.9 nF which corresponds to the frequencies 20.76 kHz, 15.46 kHz and 10.36 kHz according to the formula:

$$f = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

The transient frequencies are not quite as high as the frequency that the energy meter transmits on but the overtones will reach the desired area.

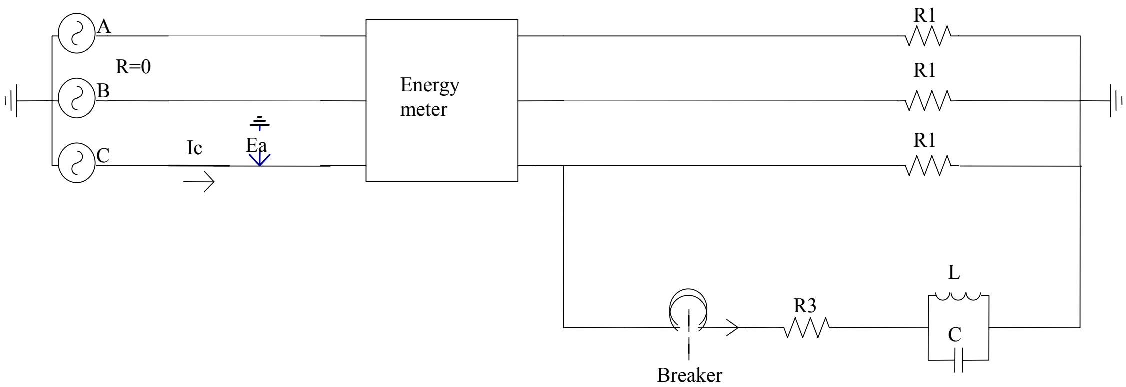

Figure 17. *Coupling where the parallel branch consists of a resistor in series with an inductance in parallel with a capacitance*

As seen on the waveforms (figure 18) created by the switch-off of the parallel branch the voltage transients correspond quite well to the calculated frequencies.

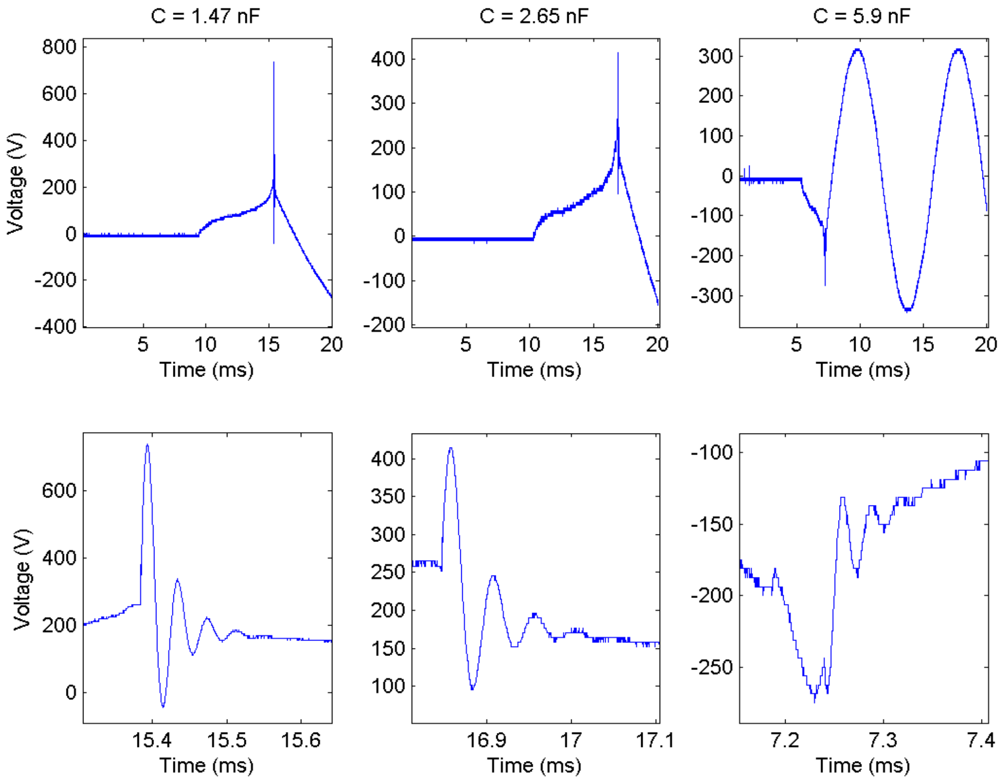

Figure 18. *Voltage transients measured on the breaker when the parallel branch is disconnected with different capacitance values and close-ups of the transient frequency in each case.*

With the components in the previous coupling there is also an option to connect them in series with each other. Essentially it is the same coupling as the previous ones, but in this setup (figure 19) all three frequencies are mixed together on the same line, creating a noisier environment since the overtones fill in the gaps between the original frequencies.

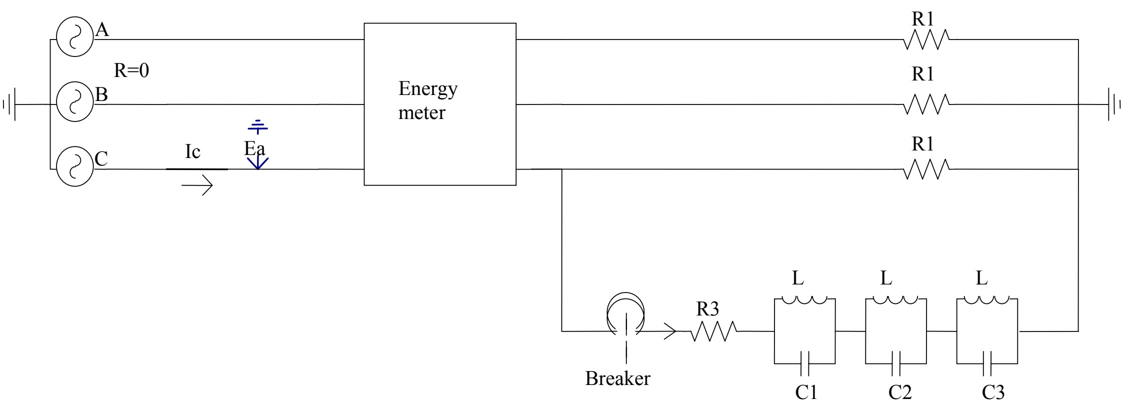

Figure 19. *Coupling where the parallel branch consists of a resistor in series with three parallel inductances and capacitances*

This also shows on the waveforms (figure 20), where there it is not visible which frequencies that are present, since they have merged together into a resulting transient.

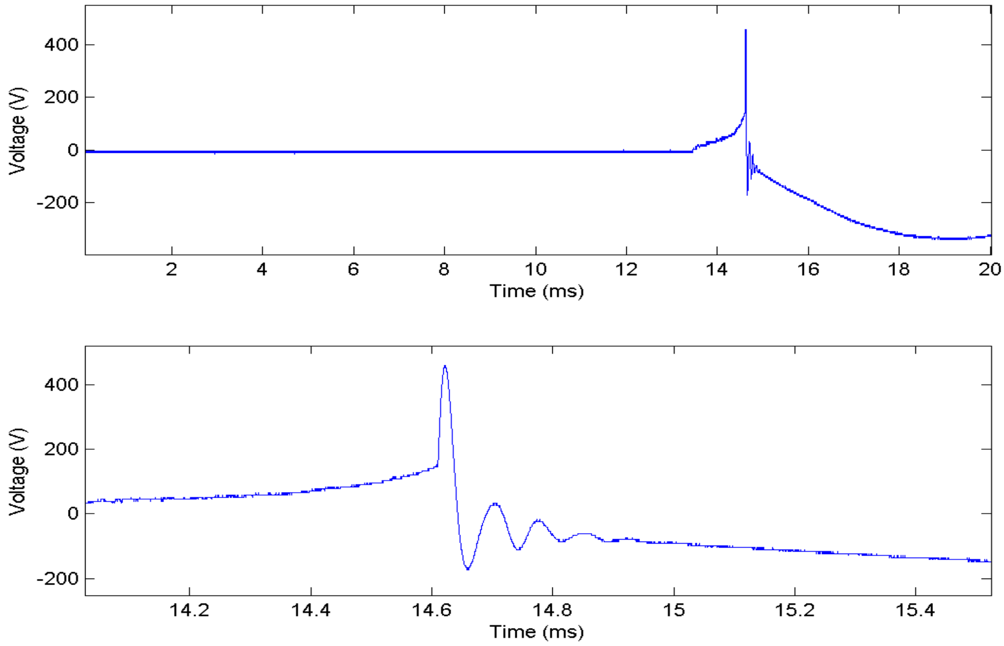

Figure 20. *Voltage transients measured on the breaker when the parallel branch is disconnected with three parallel couplings in series and a close-up of the transient frequency*

The last user made coupling (figure 21) was used for the reason that according to the manufacturer, if communication was to be disturbed all three phases must be affected. Although the net is not disturbed at the same frequencies on every phase, there are still transients present at all phases. The parallel couplings on each phase are the same as used earlier in this chapter, hence the same frequency of the transients.

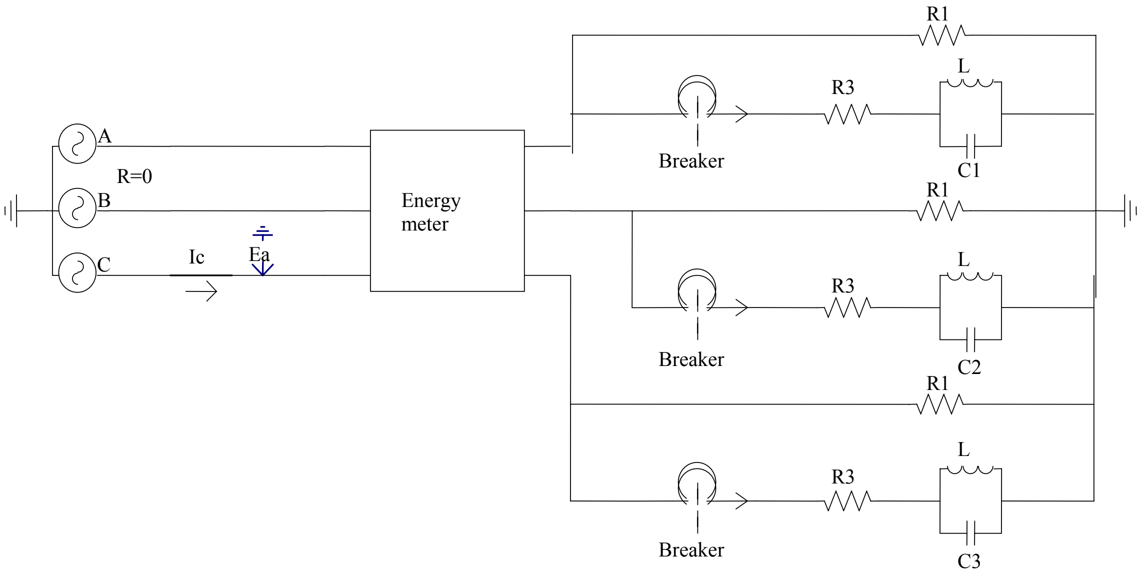

Figure 21. *Coupling where the parallel branches consists of a resistor in series with an inductance in parallel with a capacitance on all three phases*

As seen earlier the burst generator was able to disturb the communication to the degree that the information sent did not get through to the main system. But during those tests the disturbing transients came from the net side of the energy meter. With these couplings the transients came from the load side of the meter. The setup in figure 21 was first used since it disturbed all the phases and just like the burst generator it managed to block the system, but not change any values of the transmitted data. Next a disturbance on only one phase was tested, something that should not be able to disturb the system. But it worked just like the other two tests with similar results. When examining the different phases it became obvious that the transients propagated to the other phases and thereby caused enough disturbances to affect the communication. This is important since most loads in a household are single-phase loads, which means that the communication could be disturbed by a transient caused by basically any load in the net.

7.2.3 Coupling where the parallel branch consists of common household products

All of the components used to create the transients in the previous chapter were made especially to disturb the system. In this chapter the equipment used to create the transients are common household products. The products used were a television (figure 22) and a computer (figure 24). In these test there were no switch to activate the transient generating coupling but instead the existing power buttons on the products were used.

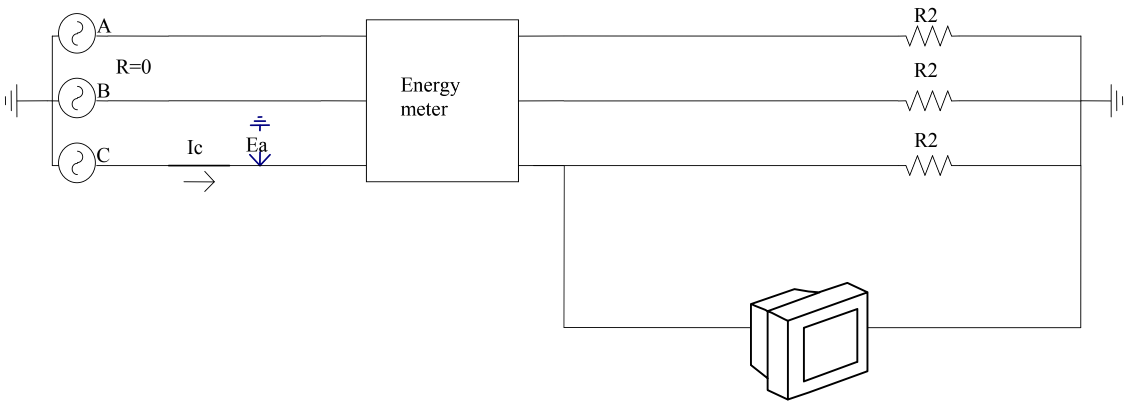

Figure 22. *Coupling where the parallel branch consists of a television*

Regarding the TV the transients generated were quite similar on the current and the voltage (figure 23), and it also caused the curve shapes to alter a bit.

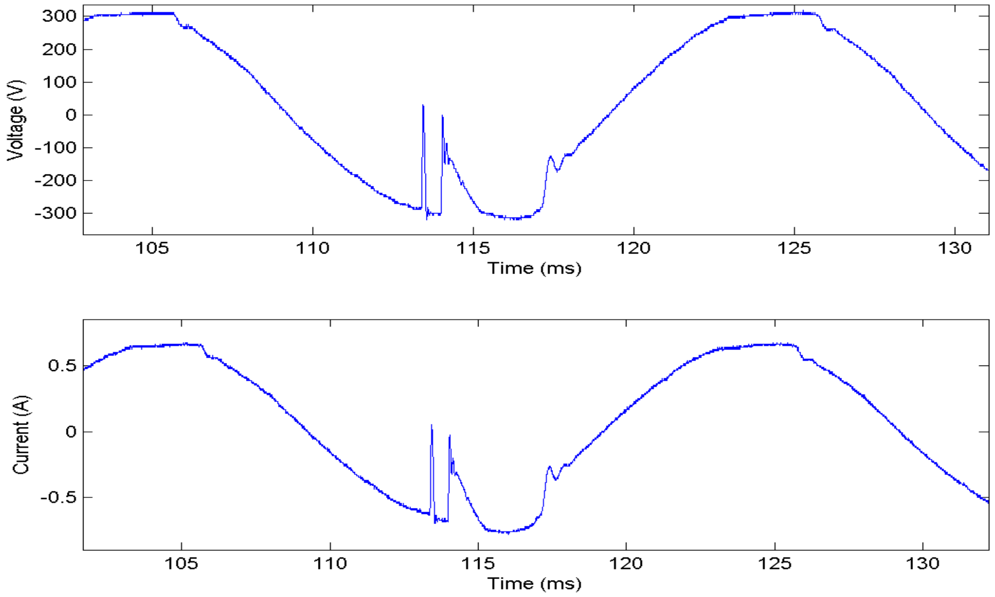

Figure 23. *Transient caused by TV energizing in both current and voltage*

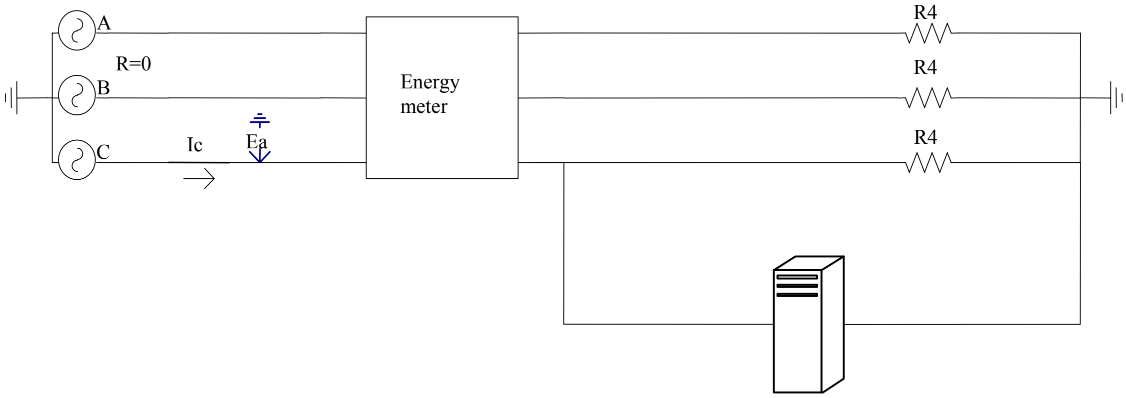

Figure 24. *Coupling where the parallel branch consists of a computer*

The result of the computer turn on caused quite a current spike and a voltage spike with smaller amplitude, at least in proportion to the rest of the curves. Also the computer caused the curve shapes to alter.

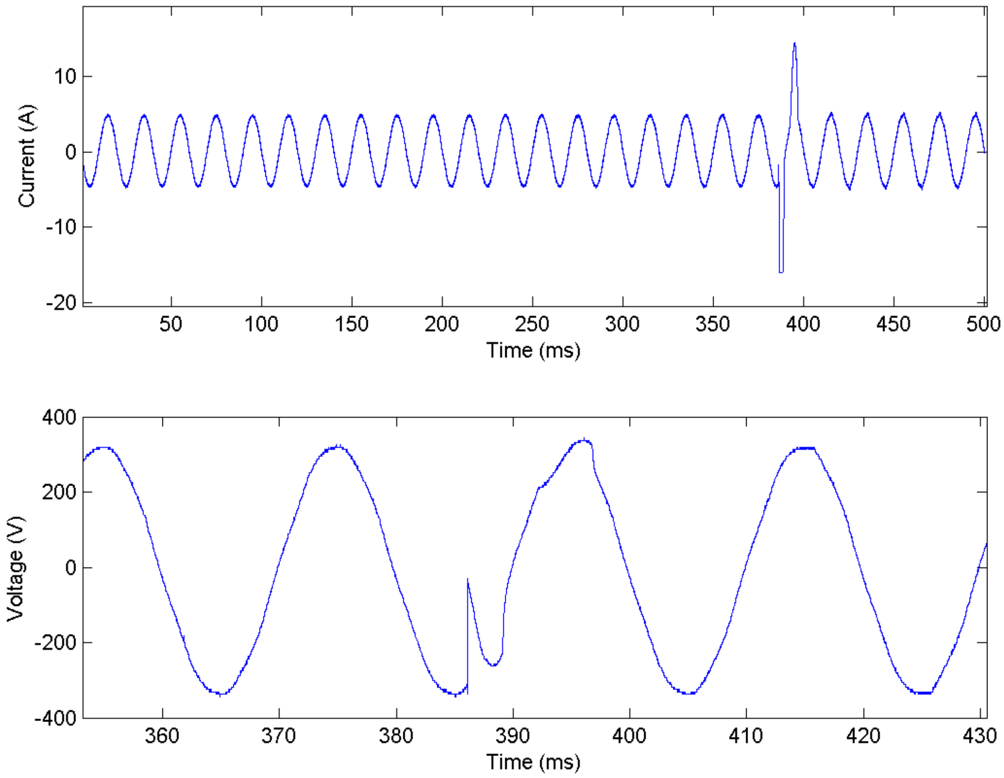

Figure 25. *Transient caused by computer energizing in both current and voltage*

The question was if the transient created would manage to disturb the communication of the system. The answer was that they would. Just like the other single-phase disturbance the transients propagated to all phases and apparently the reactance of the TV and computer caused transients with high enough frequency to propagate into the frequency range where the transmissions took place.

Discussion

A difficulty encountered during this thesis work was to actually get hold of the equipment that would be needed for the experiments. Regarding the laboratory equipment itself it was acquired quite easily with the help of some people from Chalmers and there was even a burst generator amongst the finds. After that the only thing missing were the energy meter and an AMR, which proved to be a bit harder to get hold of. Although it were just a year to go until the first stage of the introduction of remote reading should be completed when the thesis work was started, a lot of manufacturing companies either were not ready in the development of the metering system, did not have any components that they could lend out or lacked people that could be of assistance in the measuring process (or in one case the company said that their system was impossible to disturb and therefore it was no point in sending it out for testing). After three years of development only two manufacturers of seventeen (all available companies in Sweden) contacted could lend something out, one an energy meter and one a complete system.

Regarding the testing on the meters that actually were delivered it is hard to draw any real conclusions due to the small scale testing. If only the energy meter with the S0 pulse output is considered it basically all comes down to how the signal output is treated. There were clearly pulses on the output when there were transients present but the length of these pulses were only about a tenth of the pulses that were normally sent out by the energy meter. With just the meter, and no communicating equipment that should be attached to it to achieve remote reading, it is impossible to predict how the whole system would react to these pulses. The important thing the experiments made clear was that the display was not affected by the transients and showed the correct result at every instant.

With the transients made it was clearly possible to disturb the complete AMR system, not to make it send the wrong readings but enough to make system resend. This has probably something to do with the way the measured results are being handled in the software of the system. If the transmitted data does not agree with some sort of check number the reading just is not accepted by the system and therefore is not registered. It is a bit unclear how far it is between the tries and how many tries that will be sent when a measured value is blocked when the system is up and running, since in our experiments we manually acquired the read values. The important discovery the experiments have made clear was that used AMR system is able to detect all faults the created transients caused and also able to resend value readings until the process succeeded.

The frequency of the transients used to disturb the energy meters were relatively small compared to the frequencies used to transmit the data on. This is due to the fact that the amplitude decreases with smaller reactance and therefore could not be measured with the used equipment. It would be interesting to conduct further experiments with more complicated equipment to get higher up in the frequency band and make a custom-made disturbance for a system and take a look at the results in that case.

Conclusion and future work

In this thesis the laboratory tests were performed by using equipment that simulates the transients (EFT generator) and some circuit setups that generate the real transients.
The conclusion that can be made from this study is that immunity of the tested equipment (both energy meter and AMR system) is very high. The energy meter tested could not be disturbed to the degree that it could change the shown value or that any significant change in expected period time of the S0 output pulses occurred. Neither could the AMR system be disturbed to the degree that it sent wrong values or values that failed to arrive at all. This indicates that it is not likely that low voltage switching transients would cause large problems to modern energy meters or PLC communicating AMR systems.

Considering the future work of this thesis the following issues are interesting:

- Do some field measurements on existing AMR installations and do approximately the same tests but in reality and in large scale
- Investigate if voltage sags or swells harmonics, notches or other disturbances can cause problems to AMR systems
- Compare different AMR techniques with each other

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We specially wish to tank Mr. Per Holkert from Actaris Technologies AB for help and support and the lending of an electronic polyphase meter ACE3000, type 260.

Last but not least, we would like to thank Björn Fehrlund, Ragnar Quensel and Karl Thoren from IPROBE AB for their support, advices and for lending out a complete AMR system.

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Appendix A

Equipment specifications

Burst generator PB:	Haefely type PB1 serial no: PB 081293-15-89
Coupling filter:	Haefly FP 16/3-1 serial no: FP 16/3-1-081320-05-89
Contactor:	AC1 65 A AC3 220 V 15 kW 380 V 22 kW
Oscilloscope:	LeCroy 9304CM QUAD 200 MHz 100 MS/s Model 9304CM, serial no 11067
Current Probe:	LeCroy AP011 DC-120 kHz max 150 A
Voltage Probe:	LeCroy AP032 range ±1400 V Attenuation ratio 1/200
Computer:	Dell computer corporation Serial no RM803 Model no MMP 230 V, 3 A
TV:	PEONY Color TV, TC-483P 220 V, 59 W Beijing Television Factory, China
Multimeter:	Fluke 87 AC voltage 0.7% AC current 1.0% Resistance 0.2% Capacitance 1.0%
Power Supply:	Powerbox DC power supply 6303DS

Calculation of measurement uncertainty:

$P_{off}=4\cdot 0.7+2\cdot 0.2=3.2\%$

$P_{R1R2L}=4\cdot 0.2+2\cdot 1.7+0.7\cdot 2+4.2=9.8$

$P_{on}=9.8+(0.7\cdot 2+0.2)\cdot 2=13.4\%$

$T=2\cdot P_{off}+P_{on}+\text{Oscilloscope}=2\cdot 3.2+13.4+2=21.8\%$

Appendix B

Energy meter datasheet

ACE3000

Residential Three-Phase Static Meter

- Compatible with current connection standards and installations
- Anti-tampering protection
- Simple certification process
- Export active energy measurement reliable
- Long-term performance

- ACE3000 type 260

Actaris has added a new basic three-phase static meter, the ACE3000 type 260, to its product portfolio, in response to ongoing technology evolution in the residential sector, coupled with growing customer demand for static meters.

An outstanding advantage of this compact, cost-effective meter is its easy-to-read LCD, instead of a drum register. It keeps the user continuously up-to-date with consumption and provides an optical data interface for local automatic reading by handheld units (HHU).

Long life static meter
Measurement technology with proven long-term capability, long-life components and special care in the manufacturing process guarantee consistent accuracy and reliability throughout the meter's life span. Therefore the meter is closed for life as inspection is no longer necessary.

Easy Handling and Installation
The exceptionally compact design makes the ACE3000 type 260 easy to handle and extremely efficient for large-scale residential installations. Adapted to current connection standards the meter is compatible with existing installations and test benches.

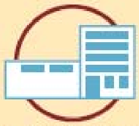
Cost Effective
With its wide dynamic range and configuration options the ACE3000 type 260 can be used for all residential applications, reducing stock costs. In addition, the meter's optical reading interface can help detect technical and non-technical losses as it can be adapted to HHU read-out systems.

Basic Residential

- Active energy measurement
- Optical read-out interface
- Diverse anti-fraud features

High Residential

- Optional double tariff system
- Efficient load management
- Active export energy
  (e.g. green energy suppliers)



Low Commercial

- Electrical pulse output
- Complete system integration
- Availability of consumption data

▶ Markets of the ACE3000 type 260

▶ ACE3000 type 260 being read

Adding Value

Through an innovative mechanical design and the application of proven, state-of-the-art technology, ACE3000 type 260 meters offer significant benefits to both utilities and end-users, adding significant value to all steps of the metering process.

Utility Benefits

▶ Reduced logistical cost
Stock can be reduced to a minimum, thanks to the compact design and extremely low weight of the meter. Five or six meters can be stacked, even with the terminal cover in place.

▶ Reduced cost for certification
Certification can be conducted very efficiently as the calibration links (I/P links) can be opened and closed without the use of screws. It is no longer necessary to inspect the interior of the meter, even as part of re-certification.

▶ Easy installation
An increased opening diameter of the mains terminals makes ACE3000 type 260 meters easy to install. All auxiliary terminals are laid out for quick connection by self clamping terminals.

▶ Reduced cost for data collection
Meter reading requires minimum effort and is very reliable because data are accessed via an optical interface.

▶ Revenue protection
Anti-fraud features, such as the permanently closed cover, protected calibration links and the unidirectional registering mode guard against human tampering.

▶ Resistance to environmental hazards
Like all Actaris meters, the ACE3000 type 260 has been carefully designed and tested to cope with severe environmental conditions, such as electromagnetic disturbances (RF fields better than 30 V/m, impulse voltage better than 8 kV) and variations of network conditions (loss of power, over- and under-voltage).

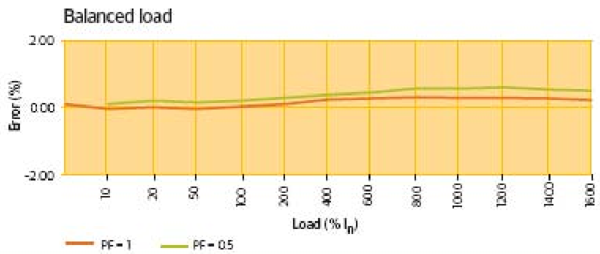
End-User Benefits

▶ Visibility of consumption
The easy-to-read LCD, especially designed for self-reading purposes, keeps the end-user informed about current operation status.

▶ Export active energy measurement
The ACE3000 type 260 meters can also be configured for measuring energy that may be exported by the end-user back into the network.

▶ System Integration
Equipped with an electrical pulse output, the ACE3000 type 260 can be integrated into the end-user's load management system.

Characteristic load curve at U_n 50Hz and at 23°C (I_n = rated current)



Key Features

Active Energy
Measurement of active energy in both directions, import and export

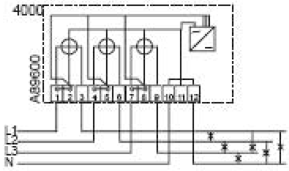
Double Tariff
Double tariff, externally controlled by time switch or ripple control receiver

Registering Modes
- Mode 1: import per phase (anti-reverse device set for each phase)
- Mode 2: Ferraris-like (simulation of Ferraris meter)
- Mode 3: unidirectional (absolute sum of import and export energy)
- Mode 4: bi-directional (import/export energy separately)

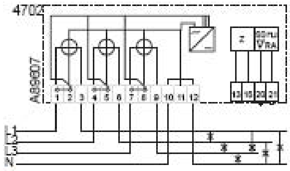
Current Range
- Dynamic range from 25mA to 100A, direct connection
- Typical load ranges 5(60)A, 5(80)A and 10(100)A

Data Output
- Data readout by optical port according to IEC 62056-21 (former IEC 61107) data with OBIS identifiers (IEC 62056-61)
- Optional with pulse output according to IEC 62053-31 Type A (S0 output) programmable for energy pulses or for serial data output

Anti-Tamper Features
- Meter housing completely and permanently closed
- I/P links can be protected (optional)
- Uni-directional mode: The meter measures absolute sum of total import and export energy
- Total reverse energy register
- Independent sealing of the meter body and terminal cover



Single tariff (DIN circuit no. 4000)



Double tariff with pulse output (DIN circuit no. 4702)

Quality

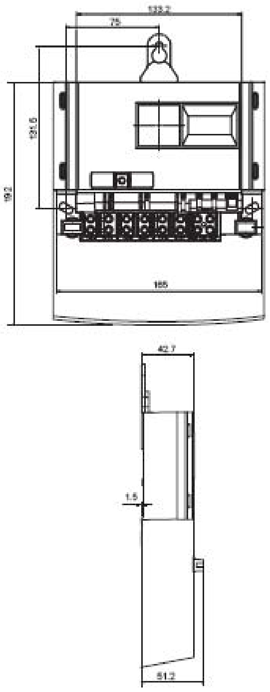
Actaris has a strong commitment to customers. In addition to standard meter tests, Actaris conducts environmental and ageing tests on product samples from the production line. These tests allow Actaris to permanently monitor not only the quality of the product but also the quality of the components supplied. The meters' efficient operation is validated in extended field trials under real conditions before they go onto the market.

The ACE3000 type 260 meter is manufactured to the highest standards of quality, reliability and accuracy and has been designed for a minimum service life of 15 years, assuring the customer's investment. Refurbishment costs over the life of the product can therefore be kept very low.

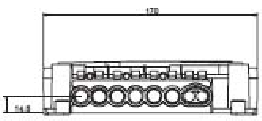
Accessories

Communications	IR-reading device
Software	Utility software for data reading
Documentation	User Guide Installation Guide Approval and test certificates

Dimensions



▶ Main dimensions



▶ Terminal arrangement

Technical Specifications

Parameter	Characteristics
Meter Type	Static polyphase watt-hour meter
Standard	IEC 62053-21:2003 for indoor application (former IEC 61036)
Network	3-phase 4-wire network
Measuring scope	Active energy in two directions (P+, P-)
Class index	Class 2.0 (optional class 1.0)
Reference frequency	50Hz
Reference voltage	3 x 230/400V
Operating voltage range	-20% to + 15% Un
Power consumption	Voltage circuit < 1.0W resp. < 2.5VA@ 230V Current circuit < 0.25VA @ Imax
Basic current	5A, 10A
Maximum current	60A, 80A, 100A
Starting current	0.4% Ib
Meter constant	1000 imp/kWh
Operating temperature range	-25°C to + 60°C
Limit temperature range of operation	-40°C to + 70°C
Temperature range for storage and transport	-40°C to + 70°C
Register type	LCD with 7 digits, size 8 x 4mm
Number of decimals	One or two decimals (configurable)
Number of rates	Double rate (optional)
Tariff control	Externally, with floated control input
Control voltage	230V
Switching characteristic	"ON" state > 80% Un, "OFF" state < 50% Un
Optical interface	according to IEC 62056-21 (former IEC 61107)
Pulse output	according to IEC 62053-31 Type A (SO output)
Terminal arrangement	According to DIN 43857 part 2
Material of current terminals	Steel, zinc plated
Diameter of current terminals	8.5mm
Diameter of neutral terminals	8.5mm
Diameter of auxiliary terminals	1.8mm (self clamping type)
Protection class	IP52 according to IEC 60529
Immunity to impulse voltages	> 8kV (1.2/50µs)
Immunity to HF fields	> 30V/m (up to 2GHz)
Meter size (W x H x D)	170 x 192 x 51mm
Meter weight	0.65 kg

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Appendix C

AMR System: The central system, meter user guide and concentrator datasheet

Automatic Meter Reading System (AMR)

AMR system

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MARATHON™

Meter reading evolvement

Meter reading is a fundamental business enabler for the utility sector. Regardless whether a utility distributes electricity, heat, water or gas there is a need to measure the consumption for each consumer. These readings are then used as a basis for billing the customer. In the past the meter reading has been done manually. Today, modern technology enables automatic remote reading and constant monitoring of meters. This concept is known as Automated Meter Reading (AMR).

Once an AMR technology has been implemented a number of features can be provided to the utility such as;

- Automatic remote meter reading (electricity, heat, water, gas)
- Individual meter reading on request
- Optimization of investments in network capacity
- Energy theft control
- Reduced administration costs for customer service center, due to accurate bills
- "Real time pricing" tool for influencing overall consumption behavior

The Marathon™-system represents a new generation AMR technology, which with new functions and improved performance offers a very cost effective solution. The introduction of millions of intelligent and communication enabled devises raises demands on operation and maintenance (O&M) well en pair with today's telephone network.

Iprobe's Marathon™-system is designed to meet these customer demands in the most cost effective way. As a result Iprobe today boasts an O&M system second to none, with features such as zero touch installation, auto configuration, auto rerouting, and full element management.

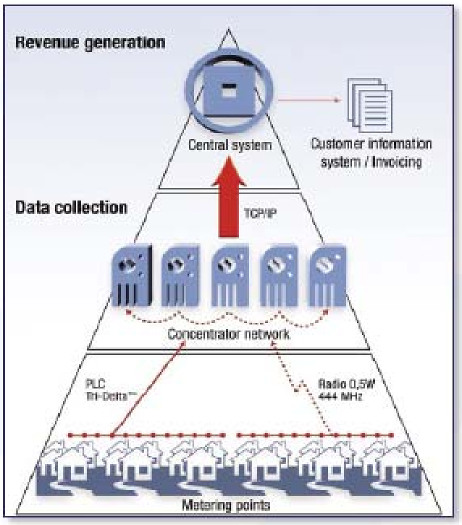

Figure 1.1 Iprobe Marathon™-system

System overview

The Marathon™-system consists of three parts:

1. Meters/terminals - equipped with communication capabilities
2. Concentrators - collecting meter readings from the meters/terminals.
3. Central system - managing the network of conentrators and meters/terminals

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The meter point

With the introduction of an AMR System the meters will, through the central system, communicate automatically with the settlement-CIS-billing systems. To achieve this in a cost effective way, Iprobe has integrated PLC (power line communication) or Radio communication technology in its meters/terminals. These two communication alternatives are working together within the same concentrator network. If the meters already installed have an interface, a terminal can read them. A terminal is typically a physical stand-alone unit connected to the meter over a common interface. The terminal is characterized by the type of access communication methodology it utilizes, e.g., PLC or Radio. PLC use the power grid itself as its transportation medium whilst radio utilizes an allocated frequency band in the air.

The concentrator

One concentrator aggregates data from up to 1024 meters/terminals. The concentrator is typically placed in the basement of a multi dwelling block (real estate owners) or in the transformer station (grid owners). The readings from the concentrators are then communicated to the central system over TCP/IP, selecting different carriers in the infrastructure (GPRS, Ethernet, Signal cable, 3GPP/TDD), depending on cost and availability. The data from the concentrators is then aggregated into the central system that acts as the controlling node in the AMR System. To optimize operating costs, the concentrators can also use its Radio communication to send stored data between themselves, thus reducing the number of GPRS subscriptions and traffic charges.

The central system

The central system implements and supports the various interfaces necessary to interact with its owner's backend systems (CIS/billing). A web interface allows users with different authorization levels to access the system through the Internet. Energy subscribers with Internet access can view their energy usage, thus adding a general awareness of their consumption behavior, and by this optimizing their energy costs. The central system also represents the operation and maintenance centre for the entire AMR system, with functions like central configuration and software upgrade of field units.

Characteristics and functions

Power line communication (PLC) is the most widely used technology for collection of meter data in advanced large-scale AMR-systems. This is due to low operational costs (no data traffic charges), ease of installation and control of the infra structure.

Iprobe's proprietary PLC, TriDelta™, has considerably higher performance than competing technology. This allows for better range as expressed as distance from terminal to concentrator and the capability to function even in severely disturbed grids. Irrespectively of how good the PLC is, it is not enough to cost effectively address all meter points. Differences in network topology and characteristics mean that in some cases PLC needs to be complemented with a radio solution. Iprobe has therefore developed a 444 MHz radio technology to work seamlessly within the same AMR system framework. This is the ideal solution for long range (up to 3-5 km) and less densely populated grids.

The function "auto discovery process" is developed to shorten the total time for system deployment and reduce operating costs over the systems lifetime. To achieve this Iprobe introduces two vital functions:

- "Zero touch installation" a highly automated installation process that reduces installation time and manually made mistakes
- Self discovery – Plug and play (PnP) is initiated when first installed or when interruption occurs in operating system

System key functions

- Aggregation of meter readings
- Multi utility reading – electricity, heat, water, gas
- Scalable from a few meters to hundreds of thousands
- Web interface with different access profiles
- Remote configuration and software download of field units
- Alarm management
- Fraud detection
- PLC and Radio communication within the same concentrator network
- Concentrator network communication
- Repeater functionality in meters/terminals
- Export features
- Java™ Web Start
- Operating system and platform independent

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Trefasmätare för aktiv elektrisk energi

Individuell elmätning

IPROBE AB

M31-1 Elmätare

- ***Enkel installation***
- ***Innovativ drifttagning***
- ***Smart kommunikation***
- ***Underhållsfri drift***
- ***Kostnadseffektiv***

Trefasmätaren M31-1 är en integrerad del i Iprobes totallösning för elmätning, Marathon™.

Mätaren bildar tillsammans med enfas-mätaren M11-1 en perfekt lösning för bostadsrättsföreningar och förvaltare som vill implementera individuell elmätning på lägenhetsnivå. M31-1 är utvecklad speciellt för individuell mätning av el, i lägenheter där mätning inte installerades när fastigheten byggdes.

Mätaren har samma goda förmåga att mäta elektrisk energi som en mätare för debiteringsmätning, och har en mycket hög kvalitet och långtidsstabilitet. Tack vare sin unika utformning är M31 mycket billigare och enklare att installera än traditionella mätare, och kan installeras på många platser där en traditionell elmätare helt enkelt inte får plats.

Elmätaren installeras direkt i anslutning till lägenhetens elcentral med hjälp av medföljande kabelsats med strömsensorer - inga extra kapslingar eller centraler krävs.

Elmätaren M31-1 kommunicerar mätarställningarna via elnätet, utan extra kabeldragning eller dyra telefonabonnemang. Kommunikationen sker via de elkablar som redan finns installerade i fastigheten. M31-1 har även en automatisk bryggfunktion som tillåter mätaren att vidarebefordra mätdata från andra elmätare i systemet.

När mätaren är installerad identifierar den sig automatiskt i systemet och mätningen är igång.

M31 garanterar på ett bekvämt sätt en rättvis och bekymmersfri mätning av er elförbrukning.

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Teknisk specifikation

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M31-1 Elmätare

Mätare

Typ	Tre fas, 4-tråds Aktiv Energi
Mätningsmetod	Strömtransformatorer, A/D omvandling och Digital signal behandling
Noggrannhet	Klass 2, EN 62053-21
Spänning	Un=3x230/400 VAC
Ström	Bas ström: Ib=5A
Max ström:	IMax=63A
Frekvens	45-55Hz
Mätkonstant (LED)	3 600 imp/kWh
Skydd	Överspänningsskydd: 12kV (SP1618)
Minne	Flashminne för lagring av 64 dygns timvärden
Data backup	>20 år, utan spanning
Optisk kommunikation	IEC 61107 för kalibreringsändamål

Kommunikation: Power Line Communication (PLC)

Modulation	A-Band – DSSS single side band B, C och D-Band – FSK
Media access metod	CSMA – C-Band Master/slave B, D band
Överföringshastighet	78, 157, 316, 631, 1262, 2525, 5050 bps
Kanaler, tillgängliga för alla tre faser	A-band – 8 DSSS koder B-band – 3 frekvenser C-band – 1 frekvens D-band – 1 frekvens

Kommunikation funktioner PLC

Konfiguration	Automatisk nätkonfiguration och val av fas och kanal. Självläkande vid ändrade förutsättningar.
Felkorrektion	Avancerad felkorrigering med konfigurerbar redundans.
Säkerhet	Verifierade och integritetsmärkta meddelanden via SHA1/HMAC signatur.

Intern klocka

Noggrannhet	1 sekund / 24h (vid 25°C omgivande temperatur)
Backup-time	72h ((vid 25°C omgivande temperatur)
Synkronisering	Varje 24h-period med centralsystemet

Låda, Dimensioner & Temperaturer

Låda, chassi	Polycarbonat IP 51
Isolering	Skyddsklass II
Dimensioner mm	H=165 W=175 D=68.5
Vikt	< 0,85 kg
Temperatur	Drift: -10°C..+ 45°C LCD: -20°C..+ 55°C Lagring: -40°C..+ 70°C NH

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Multipunkt lågspänningskommunikation

Mellanlagringsenhet

IPROBE AB

C31 Multipunkt

- ***Enkel installation***
- ***Innovativ drifttagning***
- ***Smart kommunikation***
- ***Underhållsfri drift***

Mellanlagringsenheten, Imaster C31 är det intelligenta gränssnittet mellan centralsystemet ISAC™ och mätpunkterna. Den installeras enkelt på en central plats i elnätet och kräver ingen drifttagning eller underhåll.

Vid installation spelar det ingen roll om mätare eller multipunkt installeras först, multipunkten driftsätter datainsamling och optimerar kommunikationen med den utrustning som finns installerad.

Imaster består av utrustning för att kommunicera med centralsystemet och utrustning som gör elledningarna till ett nätverk som det går att kommunicera på (PLC). Utrustningen hanterar underhållsfunktioner, som att optimera kommunikationen, hantera nyanslutna mätpunkter och säkerställa datum och tid i mätaren.

Varje Imaster C31 fungerar självständigt och är fullt kapabel till att parallellt utföra kommandon, ta emot mätdata från mätpunkter, och vidareförmedla denna till centralsystemet. En multipunkt kan adressera och hantera 1024 elmätare eller terminaler.

Elnätskommunikationen är mycket robust och Imaster C31 använder det unika gränssnittet TriDelta™.

TriDelta™ tillåter optimering av kommunikationen genom att använda samtliga tre faser, utnyttja avancerade algoritmer för optimering av överföringsfrekvens, hastighet och bästa fas för att alltid säkra bästa tänkbara kommunikation.

Kommunikationen mellan Imaster™ och centralsystemet sker huvudsakligen via TCP/IP, och C31 är i sitt grundutförande utrustad med anslutning för 10/100BaseT Ethernet vilket gör den enkel att ansluta till GPRS eller DSL.

Multipunkten kan även kompletteras med ett 0,5 W radiomodem vilket tillåter att flera multipunkter delar på en anslutning till centralsystemet.

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Teknisk specifikation

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C31 Multipunkt

Kraft och skydd	
Spänning	Un=3x230/400 VAC
Frekvens	45..55Hz
Effektbehov	
Skydd	Överspänningsskydd: 12kV (SP1616)
Standard	EN 60950
Core	
Processor	ADI Blackfin
Minne	Flash 2 MB SDRAM 16 MB CF-Card 32 MB, 64 dygns timvärden för 1024 mätare
Data backup	>20 år, utan spänning
WAN	
WAN Gränssnitt	IEEE 802.3 10/100Base-T
Optioner	GPRS transceiver modul 433/444MHz radio transceiver
WAN Protokoll	TCP/IP, SSL
C31 till C31 Gränssnitt	IEEE 802.3 10/100Base-T 444 MHz Radio (valfri)
Kommunikation: PLC – TriDelta™	
Modulation	A-band – FSK eller DSSS single side band B, C, D-Band – FSK
Mediaaccess	CSMA – C-Band Master/slave B, D band
Överföringshastighet	78, 157, 316, 631, 1262, 2525, 5050 bps
Kanaler, tillgängliga för alla tre faser	A-band – 5 frekvenser, 8 DSSS koder, B-band – 3 frekvenser C-band – 1 frekvenser D-band – 1 frekvenser
Kommunikation: Trådlös 444 och 433 MHz radio	
Modulation	FSK
Media Access Metod	Master/Slav
Överföringshastighet	2400 bps
Kanaler	444 MHz – 3 frekvenser 433 MHz – 3 frekvenser
Kommunikationsfunktioner PLC och radio	
Konfiguration	Automatisk nätkonfiguration och val av fas och kanal. Självläkande vid ändrade förutsättningar.
Felkorrigering	Avancerad felkorrigering med konfigurerbar redundans
Säkerhet	Verifierade och integritetsmärkta meddelanden via SHA1/HMAC signatur.
Intern klocka	
Noggrannhet	1 sekund / 24h (vid 25°C omgivande temperatur)
Backup-time	72h (vid 25°C omgivande temperatur)
Synkronisering	Varje 24h med centralsystemet
Låda, dimensioner & Temperaturer	
Låda, chassi	Metall, IP 51
Isolering	Skyddsklass II
Dimensioner mm	H=255 B=180 D=64
Vikt	< 1.5 kg
Temperatur	Drift: -25°C..+ 55°C Lagring: -40°C..+ 70°C NH
Interface Connectors	Terminaler, spänning och PLC, RJ45, Ethernet, Extern radioantenn FME/M, Extern GPRS antenn

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Appendix D

Matlab files

```
clear;clc;close all;% component values are to be taken as experimental ones
format long
R1=49.3;R2=96.2;R3=49.6;R4=49.6;w=100*pi;U=230;L1=0.04;C1=0.00000000147;
Ton=[0.652 0.5532 0.6507 0.5481 0.477 0.6678 1.1028 1.5762 1.6591 1.0340];
L2=0.04;C2=0.00000000265;L3=0.04;C3=0.0000000059;pc1=(((L1)/(C1))/(i*w*L1+1/(i*w
*C1)))+R2;
Poff=(U^2/R1)+2*(U^2/R3);pc2=(((L2)/(C2))/(i*w*L2+1/(i*w*C2)));
pc3=(((L3)/(C3))/(i*w*L3+1/(i*w*C3)));Ytotphase3=R1*(pc1+pc2+pc3)/(R1+pc1+pc2+pc3
);
Itot=sqrt(2)*U/abs(Ytotphase3)
Islag=(angle((R1/(R1+pc1+pc2+pc3))*(U/Ytotphase3)))%(180/pi)*
Is=(R1/abs(R1+pc1+pc2+pc3))*Itot
PLC=(U-(R2*Is/sqrt(2)))*Is
PF=cos(atan(imag(Ytotphase3)/real(Ytotphase3)))
Pphase3=(U^2/abs(Ytotphase3))*PF;
Pon=2*(U^2/R3)+Pphase3;1.4397
Tcalc=Ton*(1-(Pon/Poff))+(7200/Poff)
Treal=[2.1974 2.1973 2.1928 2.1874 2.2005 2.1812 2.2025 2.1763 2.1384 2.1673];
Tdiff=Treal-Tcalc
Tdiffproc=100*Tdiff./Tcalc
Wone=sqrt(1/(L1*C1));Wtwo=sqrt(1/(L2*C2));Wthree=sqrt(1/(L3*C3));
Fone=Wone/(2*pi)
Ftwo=Wtwo/(2*pi)
Fthree=Wthree/(2*pi)
for t=1:30000
   pc1c=Is*w*(((cos(w)-cos(Wone*(t/1000000)))/(C1*((Wone^2)-(w^2)))));
   pc2c=Is*w*(((cos(w)-cos(Wtwo*(t/1000000)))/(C2*((Wtwo^2)-(w^2)))));
   pc3c=Is*w*(((cos(w)-cos(Wthree*(t/1000000)))/(C3*((Wthree^2)-(w^2)))));
   R2c=Is*R2*sin(w*t/1000000);
      Vtr(t)=pc1c+pc2c+pc3c+R2c;
end
plot((0.000001:0.000001:0.03000),Vtr);
hold on
for k=1:30000
      V(k)=230*sqrt(2)*sin((w*k/1000000)+(Islag));
end
plot((0.000001:0.000001:0.03000),V,'r');
hold on
for n=1:30000
      Vtrs(n)=Vtr(n)+V(n);
end
plot((0.000001:0.000001:0.03000),Vtrs,'c');
%**********************************************************
```

```
%*********************************************************
format long
clc;close all;clear all;
R2=[80.3 70.5 61.7 54.8 49.3];
L=0.04;R1=496;R3=49.6;R4=49.6;om=100*pi;U=230;
Ton=[1.1568 1.0606 1.1289 0.9351 0.7289];
Poff=(U^2/R1)+2*(U^2/R3);
for k=1:1:5
 pR1andR2L=(R1)*((R2(k))+i*om*L)/((R1)+(R2(k))+i*om*L);%total impedance of
□arallel circuit
 pR1andR2Lav(k)=abs(pR1andR2L);%absolute value of
 IpR1andR2L(k)=sqrt(2)*U/pR1andR2Lav(k);%amplitude value of current
 PFpR1andR2L(k)=cos(atan(imag(pR1andR2L)/real(pR1andR2L)));%cos fi
 Pr1r2L(k)=(U^2/pR1andR2Lav(k))*PFpR1andR2L(k);%active power in series R1,R2 and L
 Pon(k)=2*(U^2/R3)+Pr1r2L(k);%active power in all phases if □arallel circuit on
 Tcalc(k)=Ton(k)*(1-(Pon(k)/Poff))+(7200/Poff);
end

%IpR1andR2L
%PFpR1andR2L
Tcalc

%**************************************************************

format long
R2=[496 243 171.3 119.4 96.2 80.3 70.5 61.7 54.8 49.3];
C=0.000050;R1=243;R3=49.6;R4=49.6;om=100*pi;U=230;Ton=0.88;
Poff=(U^2/R1)+2*(U^2/R3);
for k=1:1:10
 pR1andR2C=(R1)*((R2(k))+1/(i*om*C))/((R1)+(R2(k))+1/(i*om*C));;%total impedance of
parallell circuit
 pR1andR2Cav(k)=abs(pR1andR2C);%absolute value of
 IpR1andR2C(k)=sqrt(2)*U/pR1andR2Cav(k);%amplitude value of current
 PFpR1andR2C(k)=cos(atan(imag(pR1andR2C)/real(pR1andR2C)));%cos fi
 Pr1r2C(k)=(U^2/pR1andR2Cav(k))*PFpR1andR2C(k);%active power in series R1,R2 and L
 Pon(k)=2*(U^2/R3)+Pr1r2C(k);%active power in all phases if parallell circuit on
 T(k)=Ton*(1-(Pon(k)/Poff))+(7200/Poff);
end
clc
IpR1andR2C
PFpR1andR2C
T
%***************************************************************
```