17th Symposium IMEKO TC 4, 3rd Symposium IMEKO TC 19 and 15th IWADC Workshop
Instrumentation for the ICT Era
Sept. 8-10, 2010, Kosice, Slovakia

Electric Power Grid and Measurement Tasks in the European Union

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Abstract- Over the last years, the structures of electrical power supply changed noticeable. Centralistic conventional power generation is supplemented by distributed energy resources. Trends of energy demands let know that amount of solar and wind energy will progressively increase, very often with a relevant amount of distortion: this gives emphasis to power quality evaluation. Proper metering in non-sinusoidal conditions and, thus, large bandwidth transducers are required. Two different approaches to solve the problem of classical instrument transformers are proposed: one is substituting them with new low cost insulated electronic transducers, another is improving performances of the already installed IT, through the use of digital compensation devices. It has been proven that both the solutions solve the problems of high accuracy and large bandwidth, necessary for accurate measurements in new energy scenario.

I. Introduction

Trends of energy needs suggest that the consumption of electricity worldwide will increase by about 70% by 2030 0. At the same time, the emissions of greenhouse gases into the atmosphere, already likely to jeopardize the ecosystem, are bound to increase, unless there is a definite change in production mix. Moreover, the promotion of renewable energy has an important role to play in addressing the growing dependence on energy imports and in tackling climate change.

For this reasons, Europe Union's (EU) strategic objective is to achieve in any event, at least a 20% reduction of greenhouse gases by 2020 compared to 1990. In addition, 2050 global emission must be reduced by up to 50% compared to 1990, thus implying reductions, in industrialised countries, of 60-80% compared to 1990. In Europe Union (EU) energy accounts for 80% of all greenhouse emission and with current energy policies global emissions would increase by around 50% by 2030; moreover import dependence, with "business as usual", will register imports of gas to increase from 57% to 84% and of oil from 82% to 92% from today to 2030. In this outlook it is noticeable that electrical energy which is responsible of about 61% of overall emissions.

Looking to electricity, responsible of about the 60% of overall emissions, the total of actual European production roughly depends for about 55% from coal and gas/oil, 10% from renewables, 35% from nuclear. In this situation it is clear that the mix has to change, increasing the percentage of clean, efficient and affordable energies. The end-point is clear, but the road-map is difficult to define as it depends on many circumstances as:

- carbon, gas and oils will remain, for many years, the most important energy sources in the world; in fact there is no doubt about log-term resources availability, time life of the majority of existing plants is not expired, big investments were made on gas-oil ducts, renewable energies cannot give assurance on their growing rhythms;
- renewable industry yet depends on subsidies and it is necessary to promote further researches to bring related energy production to 20% of overall electricity demand;
- nuclear power is less sensitive to fuel price changes respect to coal and gas/oil and could provide clean and low-cost energy. On the other hand, the construction of new power plants, who are capital intensive, requires a rough investors confidence on political stability in construction areas, has to face with population fear on engines breakdown and on possibility of a distorted use of nuclear technology to war scope.

The described scenario applies with remarkable differences in EU member states due to their heterogeneity. Some of them have a significant competitive advantage, having originally opted for a massive use of nuclear energy (i.e. France) and then they have energy at low cost, non-polluting, low dependency on other supplier. In countries, including Germany, the debate on the permanence or otherwise of nuclear power is open, but in the meantime have made massive investments in research and development in the field of energy production from alternative and if they produce the components. Finally, there are countries such as Italy, heavily dependent on the production on imported fossil fuels, which greatly improves the average return of modernizing production facilities but exposes them on the front of the availability and cost of fuel.

The integration of renewable energy sources into the electric energy system has become an important challenge for the utilization and control of electric power systems aiming to economic effectiveness, environmental sustainability and reliability in supply [2]. In addition, new metrological issues arise and this paper will focus on their key features.

II. Power System Issues

Over the last years, the structures of electrical power supply changed noticeable. Centralistic conventional power generation is supplemented by distributed energy resources. The reliable operation of future energy supply structures with high share of distributed generation and renewable energy sources is an important and highly complex task. In fact, renewable energies are environmentally focused but the output power fluctuation due to the fluctuating and intermittent behaviour of wind and solar power generation may cause excess variation of voltage or frequency of the grid with remarkable stability problems. Additional issues are the poor predictability of power availability and the missing controllability. In fact, when the wind dies down or the cloud cover rolls in, the power production decreases. If the grid is relying on power contributions from a renewable plant, these natural occurrences can cause flicker on the power system loads.

In addition, because of the conversions (AC-to-AC or DC-to-AC) and the intermittency involved with renewable energy technologies', power quality often becomes an issue when the plant is connected to the main power grid. With solar power, the photovoltaic cells produce a DC current under steady sunlight. The DC current is then converted to AC via a power electronic DC to AC converter. The AC output of the power electronic converter is not an ideal sinusoid. Depending upon the quality of the equipment, the converter output may differ from the grid voltage in magnitude and frequency to some degree. This can cause quite costly damage to surrounding loads from the introduction of harmonic current injections into the system. The induction generators used in modern wind turbines also present problems for interconnected power systems. The induction generators produce power in such a way that it requires varying degrees of reactive support from the grid. Since utilities do not profit from producing reactive power, there active support tends to add an unnecessary expenses for the utility [3].

III. New Measurement Tasks

From the above described situation we may infer that :

- amount of solar and wind energy will progressively increase, becoming relevant in comparison with overall instantaneous production; as their availability will not be continuous, depending on availability of primary sources, it will be necessary to face with stability problems and connection rules;
- progressive growth of production from renewable energies, very often with a relevant amount of distortion, together with increase of non linear loads will, give emphasis to power quality evaluation. It will be very important the correct identification of distortion sources, to assess whether a load is causing current distortion, and hence should be compensated, or if the main already presents a distorted voltage and it would be necessary to improve generation and transmission characteristics;
- further development of interconnections and cross border trade of electrical energy will progressively strengthen the importance of energy and power quality certificated measurements, together with the ascribing capacity of "non quality" responsibility;
- mainly utilised electromagnetic transducers doesn't have a pass-band, in presence of high distortion rates, able to allow energy and quality measurements with the required uncertainty level.

The main problems, related to fluctuating and intermittent generation, stem from the needing to perform both active and reactive energy metering in non sinusoidal conditions. In fact, flow of non-active energy caused by non-sinusoidal currents and voltages but also the energy dissipated in the neutral path due to the zero-sequence current components has remarkable economical significance and it could significantly affects system efficiency.

Nevertheless, the scientific community discussed the problem of power definition in non sinusoidal and/or unbalanced condition during the last 30 years, and different proposals can be found in engineering literature. In fact, the mechanism of electric energy flow in these conditions is still a topic of discussion. A big contribution to the discussion comes from the latest IEEE standard about definition for measurements of electrical power quantities [4]. It clearly defines the way to perform measurements, even with different approaches, of the most important electrical power quantities under sinusoidal, non-sinusoidal, balanced or unbalanced conditions such as apparent, active and reactive power and power factor. The standard helps to single out the situations when a not correct implementation of power quantities measurements leads to wrong metering, too.

On the other hand, the latest IEC standard, [5], for characterization of the accuracy of static active meters takes as reference sinusoidal conditions and some power quality phenomena are only accounted as influence quantities that change the accuracy of meters. IEC standard for characterization of the accuracy of static reactive meters applies for sinusoidal currents and voltages containing the fundamental frequency only, [6], no reference is made to what should be measured in situations with harmonic distortion.

In this way, commercial instruments, built according to IEC approach, are designed and tested mainly for sinusoidal waveforms and, at the most, additional test, are performed in specific non-sinusoidal conditions but accounting larger accuracy tolerance,. Moreover, since there is no clear reference to which algorithm should be used for digital metering, different manufacturers adopt different implementations, equivalent in sinusoidal conditions but coming out with very different results when utilized with distorted current and voltage waveforms.

In order to fully define the product energy in generation, transmission and distribution stages and to economically regulate how energy is sold by electrical utilities and bought by final users, proper metering in non-sinusoidal conditions is required. First of all, there must be an agreement between utilities and customers with respect to the quantities that should be measured or monitored for revenue purposes and determination of major polluters. Then, a digital energy meter that is able to perform the proper metering strategy has to be adopted.

Then, the accuracy of energy meters have to be evaluated in actual working condition according latest standards about confirmation of measuring instrument [7]. That implies accounting distorted signals and/or unbalanced sequences with different levels for fundamental frequency deviation, waveform distortion, harmonic frequencies, voltage unbalance, zero sequence, and so on. Tests have to include also the combination of these phenomena because they could have a synergic effect on the measurement error.

Starting from all these considerations, from metrological point of view, the verification of energy meters becomes a strong need but, at the same time, a very complex task; in fact, a full analysis of all influence parameters, that lead to non sinusoidal condition, and all their combinations require a huge amount of tests.

IV. Certified Measurement Laboratories

The aforementioned aspects point out to a metrological nature problem, which in a modern and civil country must be solved: the possibility to carry out certified measurements of electrical energy in the actual operation conditions. The metrological quality must be, therefore, achieved and insured, first of all, inside of the organizations, manufacturers of assets and services, first and main "generators" of quality, in the shapes and degrees applicable to the correspondent production processes. The attainment of such important and not easy objective is essential for the validity and the credibility of the evaluation activities of conformity of the third part (tests and measurements, certifications of products and systems, inspection activities), carried out by an independent certified organism to the end of assurance of the quality to the market and creation of the confidence in the supplied results [8]. The organisms certified to such scope are also called "Metrological Laboratories" that assure an appraisal of the conformity carried out with the most elevated degree of professional integrity and technical competence in metrological field. The "Metrological Laboratories", assessing the conformity to institutional, organizational, technical and moral requirements established in the consensual technical standards and other applicable prescriptions, in such terms to create, in all the interested social and economic parts and, in particular, in the market of the customers and consumers, a high degree of confidence in their acts and the correspondents results. From the "standards" point of view, the "metrological quality" of the processes of monitoring and measurement, finds a first, even if generic, reply in applicable requirements of the principal standard in matter of management for the quality and precisely: i) Standard ISO 9001:2000 for the activities of production of general assets and services and Standard ISO/IEC 17025:1999 for the specific activities of test, measurement and calibration. More specific prescriptions are contained in the standard ISO 10012:2003 "Systems of management of the measurements -requirements for the processes and the equipments of measurement", with particular reference to the instrument measurements and, in such within, to the procedures of metrological confirmation. Useful indications are finally present in other reference standards, both generic and sectorial, not recalled here for brevity.

V. Issues in Electrical Quantities Sensing

First step to correct metering is correct sensing: in this section, issues related to sensing of electrical quantities are faced. Instrument transformers (IT) currently available for measuring harmonics are characterized with a parasitic capacitance which causes resonance problems [9]. In addition, the transformers have a nonlinear magnetization characteristic. This property causes the transformer core to saturate in some cases and to generate harmonics of its own into the measurements. Moreover, the inductive and capacitive effects, which they suffer of, strongly limit their dynamic performance. Typically, commercial instrument transformers are usable in the narrow 50-400 Hz frequency range. Obviously those limits make voltage transformers (VT) and current transformers (CT) unusable for the analyses of high frequency harmonic and of low frequency inter-harmonic components. At now, anyway, they are the most installed in utility points: so, when a new transducer is proposed, first of all its performances have to be compared with them, in terms of accuracy and cost. In the following, two approaches for solving sensing issues are proposed: the first is based on the realization of new electronic low cost transducers, the second on the compensation of existing instrument transformers.

A. Low cost and large bandwidth electronic transducers

The simplified electrical scheme of the proposed transducer is shown in [3]. It can be seen that simple electronic components, such as operational amplifiers (op-amps), resistors and capacitors have been used; in fact, one of the main advantages of this circuit is the very low cost of its components. Three main sections can be found: the first one is the input stage which couples the transducer to the voltage source, having an high input impedance; the second one is the optical insulation stage, which separate low voltage output section from high voltage input section; finally, the third one is the output stage which couples the transducer with the input stage of measuring instruments.

The input stage is basically an active compensated divider; it has been obtained by two op-amps. The current-pump configuration is used in order to obtain a current differential amplifier with the output node on the non inverting input. The entire input stage exhibits a transduction ratio of 5000:1.

An optical insulation stage has been introduced after the input stage. It consists of a modulator optically coupled to a demodulator. It guarantees insulation up to 2500 V with an upper bound on usable bandwidth at approximately 100 kHz, high enough for applications on power systems; in fact it is a very large limit compared to those present in the standards [10]-[12]. A first order analogical filter has been inserted at the input of the insulator with the aim of avoiding frequency alias.

The insulation stage receives input signals in the range of ± 200 mV and its output is the reproduction of the input but amplified with a scaling factor of 10. An output differential stage has been used: it amplifies the output of the optical insulator with a scaling factor of 5 and it has a -3 dB 100 kHz bandwidth. The so implemented transducer exhibits a transduction factor of 100. Moreover, it has two different outputs: one is analogical, the other one is a buffered high speed serial output, obtained by means of an opportune microcontroller. In this way, the transducer is made more versatile; in fact, basing on the used measuring instrumentation, it can be decided to use digital or analog output. Ratio error and phase displacement of realized transducer are shown in Figure 1. It can be seen that the phase shift introduced by the realized transducer increases logarithmically; that is it increases linearly with the frequency. This is due to a constant time delay in the optical insulator; it can be compensated in post-processing. Ratio error is equal to 0.11 % and phase displacement to 0.1 mrad.

Basing on the presented scheme, a current transducer from the voltage one can be realized: it is obtained changing only its input stage.

B. Technique for compensating instrument transformers

Some techniques for compensating VTs and CTs are present in scientific literature [13]. The following technique has been applied, only for sake of brevity to a current transformer (CT): also a voltage transformer can be compensated through this technique. If the CT has got a low linearity error, it can be considered as a linear system and its frequency response is given by (1):

$$Y(f) = \frac{1}{R(f)e^{-j\varphi(f)}} X(f) \tag{1}$$

where X is the input, Y the output, R and φ respectively the transduction ratio and the phase displacement defined in [13]. Therefore, in order to eliminate the frequency dependence in (1), a digital filter has to be found, which has got a frequency response given by (2):

$$H\left(e^{j2\pi f T_s}\right) = R(f)e^{-j\varphi(f)} = \frac{X(f)}{Y(f)} \tag{2}$$

where H is its frequency response and T_s is the sampling period. Such identification problem is an optimization problem and so an objective function has to be defined and minimized through an optimization algorithm.

The technique for indentifying the digital filter is presented in [14]. The identified digital filter has 20 zeros and 22 poles, and it represents the inverse linear system of the characterized CT; sampling frequency has been chosen equal to 160 kHz. In order to real time compensate the CT a digital processor, opportunely equipped with analog to digital and digital to analog converters, has to be used. For the case at hand, an FPGA board has been used. It has got an ADC and a DAC with 16 bit resolution and 200 kHz maximum sampling frequency for the first one, 1 MHz for the second. The block scheme of compensated CT is shown in Figure 2.

Such an instrument transformer continues to be an analog device, offering thus the possibility of being employed in whatever measuring system.

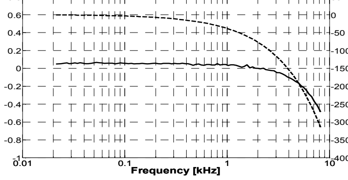

Figure 1. Ratio error and phase displacement of the realized transducer.

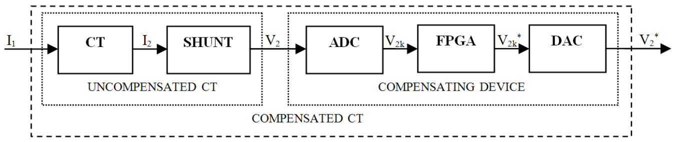

Figure 2. Block scheme of the compensated current transformer

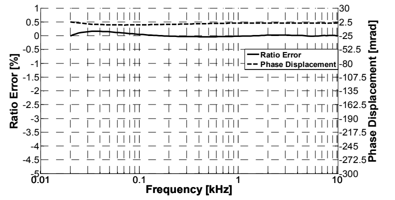

Figure 3. Ratio error and phase displacement of compensated current transformer.

TABLE I. COMPENSATION IMPROVEMENTS IN RATIO ERROR AND PHASE DISPLACEMENT

	Ratio error [%]	Imp [p.u.]	Phase displacement [mrad]	Imp [p.u.]
CT	2.182	145	173.69	347
Comp. CT	0.015		0.50	

Ratio error and phase displacement of compensated CT are shown in Figure 3. In Table I mean quadratic values for ratio errors and phase displacements of uncompensated and compensated CTs and compensation improvements are reported.

Experimental results have shown that the compensated CT improves performances of the original CT; ratio error steps up of a factor 145 and phase displacement of 347. Compensated CT has ratio error of 0.015 % and phase displacement of 0.50 mrad.

VI. Conclusions

Trends of energy demands let know that amount of solar and wind energy will progressively increase, very often with a relevant amount of distortion; this gives emphasis to power quality evaluation. Proper metering in non-sinusoidal conditions and, thus, large bandwidth transducers are required. Two different approaches to solve the problem of classical instrument transformers are proposed: one is substituting them with new low cost insulated electronic transducers, another is improving performances of the already installed IT, through the use of digital compensation devices. It has been proven that both the solutions solve the problems of high accuracy and large bandwidth, necessary for accurate measurements in new energy scenario.

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