ELECTRONIC HIGH VOLTAGE COMBINED MEASURING TRANSFORMER

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ABSTRACT

This paper describes a concept for controlling voltage profile in distribution network with dispersed energy resources (DER). This concept is based on fast communication links between checkpoints with a help of non-conventional instrument transformer (NCIT). NCIT's main advantage is the possibility to adapt measuring points in high voltage power networks with new conditions regarding impact of intermittent renewable resources, harmonic distortions due to switching apparatus, smart grid systems and satisfy the requirements for prompt and accurate measurements in wider frequency range with higher dynamics. It can also provide more reliable operations. Advantage of this concept is in establishing a reliable distribution networks with proper network voltage profile.

INTRODUCTION

Overall economic growth caused increased energy consumption of about 1.7% per year between the years 1997-2007 which caused a growth in electricity consumption of 32.8%. This is forcing the world to improve electrical power grid and to increase the production of electricity. This issue can be solved by connecting a number of DER into existing electrical power grid on middle (MV) and low voltage (LV) networks [1] which unfortunately affect the power network reliability and the network voltage profile stability [2]. It may also cause a serious damage on devices owned by the distributors as well as the users.

In the "old" power grid network (without DER), the problem with the network voltage profile was solved in the distribution transformer substations, where the voltage was equally regulated for all feeders, that were routed from one substation. This approach for controlling the network voltage profile is inappropriate in the power network with DER because of the different distribution system structure. The "old" power grid structure is designed in such a way that there are producers of electrical energy on one side of the network and the consumers on the other side. This type of networks has many positive qualities, for instance a linear voltage decrease from the transformer station to the end of the feeder. Therefore, the distributor of the electric power must ensure that across LV feeder the voltage value does not exceed legally prescribed limits. This process begins with the configuration of on-load tab-changers (OLTC [3]) in transformers between the high (HV) and MV networks and ends up with the off-circuit tabs in MV/LV transformer, which are not intended for everyday adjustments.

The problem of the network voltage profile in distribution network without DER is solved in distribution transformer substation where the voltage regulation is the same for all the feeders routed from one substation. By adding DER to a LV and MV distribution network, this procedure of controlling the network voltage profile is insufficient because of uneven distribution of the active power.

In Fig. 1, a simple example of a network with DER is shown. The power network has got three feeders which are subsets of one substation and they have connected a different number of DER on different locations over the feeder. Every DER which is connected on the feeder linearly increases the voltage value along the entire feeder and represents a local extreme in the network voltage profile.

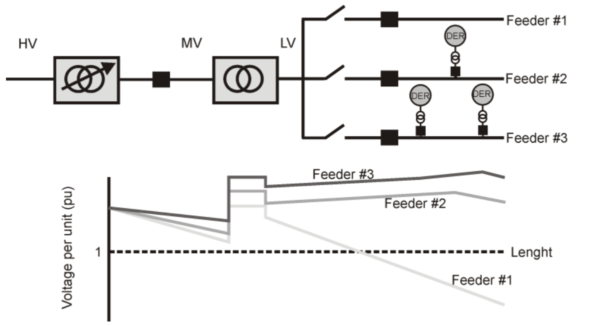

Fig. 1. Network voltage profile without any intervention

The graph in Fig. 1 shows the network voltage profile where it can be seen how the voltage varies with the length of the feeder (only feeder 1 is inside legally prescribed limits – between 0.9 and 1.1 per unit (pu)). To avoid this scenario, a new concept of communication and regulation mechanisms in distribution network is presented

CONCEPT

The existing power grid network has a wide variety of qualities, but unfortunately it also contains one negative feature – the network does not receive any feedback from MV and LV users. The solution lies in establishing a network of information and communication technologies (ICT) which will link together each element, especially the elements of production, transmission, distribution and the end-user of the electricity power network.

Every distribution network contains several levels of communication (real time, non-real time and time independent). The proposed concept consists of all these types and is based on the fast communication system between the multiple substations and the control center (Fig. 2).

The structure of the example distribution system is shown in Fig. 2, where two types of communication lines - command and task are applied. The task lines are required for the exchange of measurements and settings between the checkpoints and the Area Control Centre (ACC) where the main monitoring takes place. This communication enables supervision and exchange of information. Due to the fact that command lines transport crucial information for functioning of the distribution network between substations (such as intelligent electronic devices (IED) and advanced metering infrastructure (AMI)), they get highest priority in communication.

This concept solves two key issues. The first is establishing the communication in distribution network. It is a system which improves the overall situation view, the optimization of the power network and also responsiveness when a detection of any serious errors occurs [4].

The second issue is the control of voltage profile in the entire distribution network. The idea to achieve this goal is to install a control box before each substation, feeder, user, and DER, which is composed of two separate components (embedded PC and measuring-controlling center). This equipment is marked with a black square in Fig. 1 and as PCCI in Fig. 2.

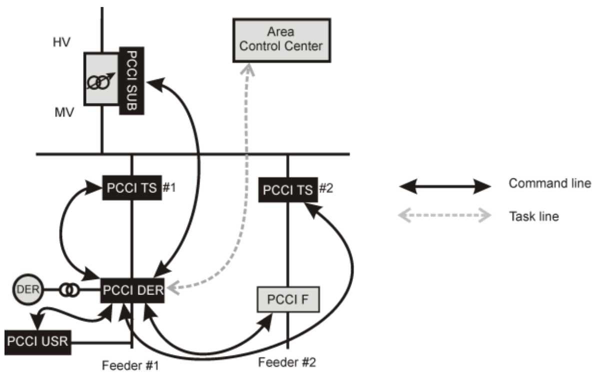

Fig. 2 Communication in low voltage network with DER

One benefit of this structure is that it acts on the spot, which is convenient for meeting other conditions and requirements of distribution systems with DER [5]. All control boxes must be:

- **Fast** – the system should react as soon as possible and thereby prevent damage to the remaining equipment.
- **Reliable** – the system should work properly in abnormal conditions or even if an error occurs in this system.
- **Sensitive** – the system should be able to detect abnormal situations, which exceed nominal permitted values.
- **Selective** – the system should switch off only a defective part and thereby minimize the consequence of an error.
- **Automatic** – the system should react in combination with the ACC to adapt network parameters.
- **Easy to install and maintain** – the system should operate on “plug and play” principles.
- **Integration into the existing control system** – the system should be compatible with the existing control system.

For a better understanding, we will call this IED - Point of Common Coupling Interface (PCCI).

The concept is demonstrated in a distribution network (Fig. 2) where five different types of PCCI (depending on the layout and function) are installed. Every network has a specific voltage profile which is formed by the present location of DER. To maintain proper voltage profile we need checkpoints with an installed PCCI. They consist of a merging unit (EMU) and security-regulation mechanisms.

It is essential to ensure real-time communication between all PCCI, which requires interaction data for the proper functioning of algorithms for regulation of the network voltage profile. It is crucial that security-regulation mechanisms have real-time measurements. These measurements cannot be ensured with conventional transformers therefore NCIT is presented. Real-time measurements are provided with EMU or in combination with NCIT in substations.

NON-CONVENCTIONAL INSTRUMENT TRANSFORMER (NCIT)

Conventional instrument transformers, which have reliably performed their tasks for many decades are not a suitable choice in forthcoming operations of electro-energetic system. The need for prompt and accurate measurements in a wider frequency range, higher dynamics, safer and more reliable operations calls for a new generation of instrument transformers. Major issues regarding conventional instrument transformers are:

- Many variations for different purposes (transient, differential, metering…).
- A lot of copper and transformer sheet metal is used.
- They demand isolation.
- Environmentally hazardous technology (oil).
- Hazardous faults (explosions when overheating).
- Big, heavy and expensive due to copper, transformer sheet metal and other precious metals.
- Lots of secondary wires and hazardous handling (open current terminals).

Proposed NCIT, which is shown in Fig. 3, solves all the described issues. Electronic measuring part within NCIT requires no environmentally hazardous transformer oil or precious metals. Currently used sensors with their wide

frequency range and wide dynamic range allow different measuring and protection operations. Such NCIT allows monitoring of all power quality indices including harmonic analysis.
Furthermore, NCIT can be easily connected to new digital protection systems incorporating IEC61850-9-2 sampled values thus avoiding heavy wiring and additional signal conversion.
Biggest concern with electronic instrument transformers is of course reliability in real-life operation. For that purpose, proposed NCIT has been a subject of testing in HV laboratory to verify its resistance to heavy disturbances in power network. After successful testing it has been installed in a substation in series with operational conventional instrument transformers for further testing purposes in real-life network conditions. After a year of operation it proved its reliability. Still further testing is required especially due to standardization requirements of IEC 61869 and other related standards for digital instrument transformers.

Fig. 3 Non-conventional instrument transformer

NCIT is similar to conventional voltage measuring transformers, using a capacitive divider, while the current measuring part floats on a HV line.
In Fig. 4 the key components of NCIT are shown. Inside of the head (1) current transformers are used – CT (2), more precisely LPCT (low power current transformer) which are normally designed for measuring and protection on middle voltage level. In NCIT two identical LPCTs are used, one for protection purposes and the other for measuring purposes, although only a single one would suffice due to their high accuracy and linearity in its extremely wide operation range.
Advantage of this NCIT is that the main measuring unit, (5) which provides fast and accurate sampling of measured voltage and current as well as time stamping of derived, is floating on HV line, therefore no extra HV isolation is required. Since the NCIT does not use HV current measuring transformers, it allows for greater accuracy of captured data even at higher frequencies and improved calculations of phase angles at higher grid harmonics [7]. For communication purposes, optical fibers are used. (6) They provide adequate isolation between ground potential and HV potential, where measuring electronics reside. Optical fibers are also used for delivering auxiliary power supply to the measuring electronics (4).

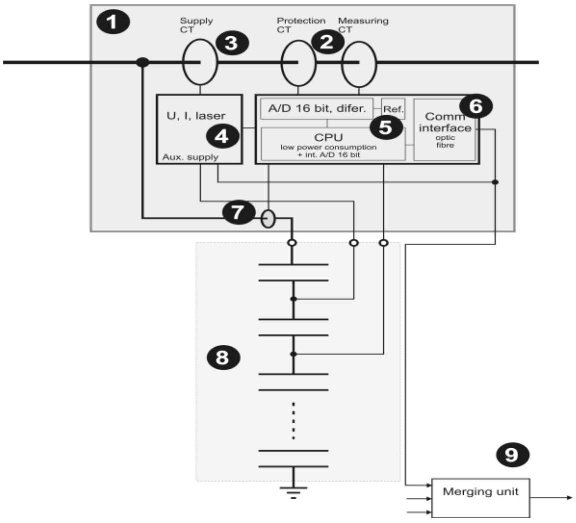

Fig. 4 Structure of NCIT

One of the most important components in the concept is EMU (9) which is shown in Fig. 5. The EMU has one three-phase voltage input and one three-phase current input, which acquires AC current or voltage signals, which are the output from instrument transformers. It converts analogue signals into digital values and transmits them using the IEC 61850 [6] standard. The values are stored as sampled values (SV) in accordance with implementation guidelines for the IEC 61850-9-2 specification. These values can be directly used by bay controllers and protective relays that support IEC 61850-9-2 protocol. The EMU has been customized to achieve the optimum operation. This was done by removing the component for A/D conversion, because the communication interface (6) can already send the measured samples and other relevant data over optical fibres in proprietary protocol. Transmitted data is stored in FPGA and mapped in standard IEC 61850-9-2. The EMU under this standard can send out 80 SV for protection causes, 256 SV for metering unit and 1024 SV for power quality check. The EMU is designed for receiving measured samples from three NCITs, reconstructing of measured signal from received samples in real time, performing all required calculations, driving analogue output required by protection relays, sending measurements through communication interface, using communication standard IEC 61850 and for directing optical communication with measuring unit inside of NCIT.
Advantage of this EMU is in the standard IEC 61850-9-2, which allows savings in the installation i.e. copper wire and space saving as a result of reduction in interferences and massive increases in safety due to the fibre-optic communications.

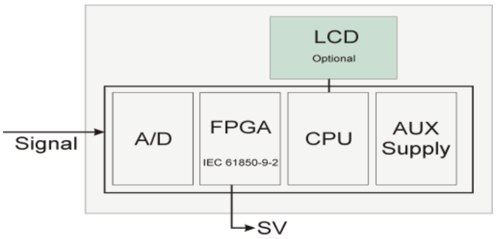

Fig. 5 Structure of merging unit

BENEFITS OF CONCEPT

The features described above for concept with NCIT deliver substantial benefits in different electro-energetic system aspects:

- **Financial aspect –** the NCIT with PCCI is much less expensive than standard HV transformers. Due to high cost of standard combined (voltage and current) transformers, two separate transformers per phase are used. Therefore in case of failure of one of them the other is still operational. In case of NCIT, which are less expensive, the decision will be to use a combined one.
- **Spatial aspect** – the PCCI and NCIT is much smaller and light-weighted than standard HV transformers and by that easier to transport.
- **Safety aspect** – the NCIT is much safer operation. In case of failure they do not explode and create heavy fires (which is very common with classic HV transformers due to heating up of isolation oil) and damage maintenance personnel and other expensive equipment on site.
- **Environmental aspect** – the NCIT has measuring electronics with CT's and optical communication interface is floating on HV level, therefore no extra HV isolation is required.

SUMMARY

The integration of the distributed energy resources is becoming an everyday occurrence, but unfortunately it affects the "old" stable and reliable electricity power network. Despite the closed environment, in which it operates, it should be guaranteed that interferences caused by activation of the DER will not influence the distribution network.

This situation can be solved with the help of the electrical and communication mechanisms which form the framework of the ICI. With this network several benefits can be obtained, such as supervision of the distribution network and the access for all the users to the internet application where the user can monitor the power consumption and specify its settings.

This paper describes the concept of a communication mechanism, which can be used for controlling network voltage profile and detecting any problems in distribution network. This concept is implemented with a help of NCIT, which is based on the use of HV capacitive divider in conjunction with measuring and process electronics. The electronics are situated partially on the potential of the HV line and partially on earth potential. They are linked by an optical link that provides real time data transfer between measuring and central processing electronics. This procedure allows a new approach to measuring all the parameters of a HV grid including measurements of energy quality in all three phase lines.

The test result shows that the proposed NCIT is equally precise as a traditional voltage and current transformer and solves many major issues in the field of HV transformers.

REFERENCES

[1] C. Wei, "A Conceptual Framework for Smart Grid," presented at 2010 Asia-Pacific Power and Energy Engineering Conference (APPEEC), Chengdu, China, 2010.

[2] T. Ackermann, G. Andersson and L. Soder, "Distributed generation: a definition," in *2001 Electric power systems research 57*, pp. 195-204.

[3] M. Joorabian, M. Ajodani, M. Baghdadi, "A method for voltage regulation in distribution network equipped with OLTC transformers and DG units," presented at 2010 Asia-Pacific Power and Energy Engineering Conference (APPEEC), Chengdu, China, 2010.

[4] D. Uthitsunthorn and T. Kulworawanichpong, "Distance protection of a renewable energy plant in electric power distribution systems," presented at 2010 International conference on Power System Technology (POWERCON), Hangzhou, China, 2010.

[5] J.Eto, V. Budhraja, C. Martinez, J.Dyer and M. Kondragunta, "Research, Development, and Demonstration Needs for Large-Scale, Reliability- Enhancing, Integration of Distributed Energy Resources", presented at Proceedings of the 33th annual Hawaii international conference on System Science, Hawaii, United States, 2000

[6] S. Weiss, P. Graeve, A. Andersson, 2011, "Benefits of converting conventional instrument transformer data into smart grid capable process data utilizing IEC 61850 merging unit", presented at *CIRED 21st International Conference on Electricity Distribution*, Paper 0472

[7] J. Meyer. R. Stiegler, M. Klatt, M. Elst, E.Sperling, 2011, "Accuracy of harmonic voltage measurements in the frequency range up to 5 kHz conventional instrument transformer", presented at *CIRED 21st International Conference on Electricity Distribution*, Paper 0917

BIOGRAPHY

Jure Močnik was born in Kranj, Slovenia in 1985. He received the B.Sc. degree from the Electrical Engineering. Since 2010 he has been a researcher at the companies Iskra Sistemi and RC eNeM in Otoče, Slovenia. Currently he is a junior researcher at the Faculty of Electrical Engineering in Ljubljana, Slovenia. His research interests include power quality, distributed generation and active network operation.

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