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Communication – control concept in the distribution power network with dispersed energy resources

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Abstract. This paper describes a communication concept in the distribution power network with dispersed energy resources (DER), which regulates and controls the voltage profile in the power network. The communication concept is based on fast links between checkpoints on feeders and on DER. The advantage of this concept is establishing communication among all DERs, feeders and the area control center, which allows them to communicate with each other at any given time without any restrictions. Another advantage is the possibility of upgrading to the existing IEC 61850 standard.

Keywords: IEC 61850, information and communication technology (ICT), dispersed energy resources (DER), smart grids, substations communication,

1 INTRODUCTION

The overall economic growth and behavior of the consumers has increased the energy consumption by some 1.7% per year over the period 1997-2007 which has increased electricity consumption by 32.8% [1]. This fact forces the world to improve the electric power grid and to increase the electricity production. This issue can be solved by connecting small wind, solar and hydro power plants, the so-called dispersed energy resources (DER), into the existing electric power grid on the middle (MV) and low voltage (LV) level [2]. These DERs unfortunately affect the power network reliability and network voltage-profile stability [3] which may seriously damage devices owned by the distribution utilities as well as users.

In a power grid network without any DER, the problem with the network voltage profile was solved in distribution transformer substations where the voltage was equally controlled for all the feeders which were routed from one substation. This approach to network voltage-profile controlling is inappropriate in a power network with DER, because of different structures of the distribution system. The "old" power grid structure is designed in a way that on one side of the network there are electricity producers and on the other side there are consumers. This type of the network has many good qualities. One of them is that the voltage decreases quite linearly with the distance from the transformer station, enabling the electric power distributor to ensure that across the LV feeder voltage value doesn't exceed the legally imposed limits. This process begins by the configuring transformers between the high (HV) and MV network, which is usually adjustable with on-load tap-changers (OLTC [4]) and ends with on MV/LV transformer. They are adjustable with off-circuit taps which are usually not used for everyday adjustments.

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

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

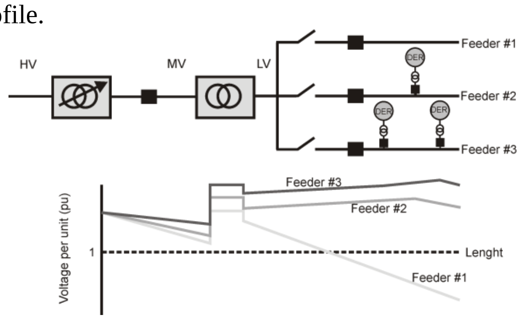

Fig. 1. Voltage profile without any interventions

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. With the light grey line it is shown how the "classic" voltage profile looks. The voltage value is reduced from initial 1.1 to final 0.9 per

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unit (pu) which is acceptable in most countries. On the contrary, if DERs are included into the power network (feeder 2 and 3), the voltage value may rise from initial 1.2 pu which is not permitted. To avoid this scenario, a new concept of communication and control mechanisms in the LV and MV voltage distribution network is presented.

2 CONCEPT

The existing power network has a wide variety of qualities but unfortunately it also contains one negative feature – it does not receive any feedback from the MV and LV users. The solution is to establish a network of information and communication technologies (ICT) which will link together each of the elements, especially the elements of production, transmission, distribution and end-users of the electric 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 - emergency and non-emergency (information) are applied. The non-emergency lines are required for sending measurement and the settings between the substations and the Area Control Centre (ACC) where the main monitoring takes place. This communication permits to supervise the exchange of the information. Due to the importance of the emergency lines they send crucial information for functioning of the distribution network between substations, intelligent electronic devices (IED) and advanced metering infrastructure (AMI), they get the highest priority in communication.

This concept solves two key issues. The first is establishing the communication in distribution a system which improves the overall situation view, the optimization of the power network and also responsiveness of detection of any serious errors [5].

The second issue is controlling the voltage profile in the entire distribution network. The idea to achieve this goal is to install a control box before each main feeder, user, and DER, which is for the time being composed of two separate components (embedded PC and measuring-controlling center), but the development proceeds in the direction of integrating both components into a single measurement-control device. This equipment is marked with a black square in Fig. 2 and as PCCI in Fig. 2.

One of the benefits of this structure is that it acts on the spot, which is convenient for meeting other conditions and requirements of distribution systems with DER [6]. All control boxes must contain specifications that should be:

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

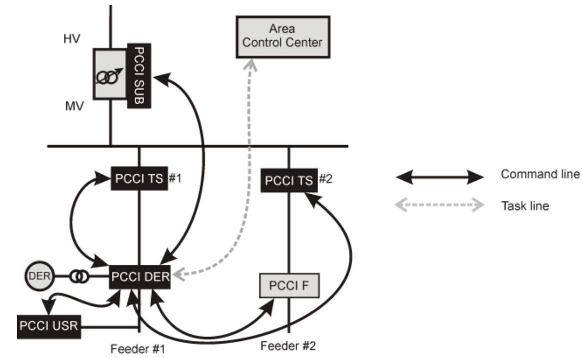

Fig. 2. Communications in distribution network with DER

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

3 METHODOLOGY OF THE CONCEPT

The proposed concept is demonstrated with the network shown in Fig. 2. Within this network, there are five different types of PCCI installed which manage specific tasks according to their position. Every PCCI can send and receive specific measurements and commands to/from another PCCI according to its requirements.

The calculation of power and energy is based on equations (1) and (2), where the energy (E) is integral of power (P) over time (t).

$$P = U_{eff} * I_{eff} * cos\,\emptyset \quad (1)$$

$$E = \int_0^T P\,dt \quad (2)$$

To calculate the power, it must be considered that the voltage and current inside of alternating circuit are not in phase, therefore the root mean square (RMS) value of voltage (U_{eff}) and current (I_{eff}) should be considered, multiplied with power factor ($cos\,\emptyset$).

Every network has the specific voltage profile [6] which is formed by the presence location of DER. Fig. 4 shows how the network voltage profile looks like if there is a differently sized DER installed on it.

Depending of the size of the currently delivered power, DER can be divided into four groups (inactive, minor, medium or major DER). Each of these groups has its own characteristics and impact on the network voltage profile which requires different solutions to manage it.

In all cases, obtaining information is the same. Every PCCI makes its own arrays (3) of data, which consist of the day of the week, time of the measurement (1 minute interval) and measurement of specific parameter (power, current, voltage…), which stores the 1 minute average value. The information is now averaged to obtain the average value for each hour, day, working week and weekend by month and season.

$$\begin{bmatrix} Mo \\ Tu \\ \dots \\ Sa \\ Su \end{bmatrix} * [00.00 \quad 00.01 \ \dots \ 23.59] * P = \begin{bmatrix} 10,43 & \cdots & 42,40 \\ \vdots & \ddots & \vdots \\ 34,35 & \cdots & 45,68 \end{bmatrix} \quad (3)$$

There are also data arrays which contain the maximum values of parameters in all of the mentioned averages. This is done to provide certain guidance in energy consumption of the consumer and to predict energy reserves calculated according to (4). In this case, P_{all} represents the entire power which is the sum of the actual use (P_{use}) and power reserve (P_{res}), which can be calculated with the power average of the last hour (P_{avgH}) and the maximum value of power (P_{maxH}) in the last hour of the month multiplied by 1.2.

$$P_{all} = P_{use} + P_{res} = ((P_{avgH} + P_{maxH}) / 2) * 1.2 \quad (4)$$

When DER is connected to the power network but is inactive, or, there is DER connected, the controlling network voltage profile using the proposed communication concept is relatively simple. All that is required is that voltage value at the beginning and at the end of the feeder doesn't fall or rise beyond the legally specified value. To ensure this, several PCCIs PLs and PCCI USRs are installed across the feeder, which provides precise information of the network status. Every PCCI sends current measurements to PCCI SUB. In this situation, there is no activity and PCCI RV sends this information to other PCCI. Unless measurement results are inside the prescribed limits, PCCI SUB calculates and sends setting to OLTC, which sets the appropriate transmission ratio and thereby determines the appropriate initial voltage.

Similar to the previous case is the situation where minor DER [7] is connected to the network. The difference is that PCCI SUB detects PCCI RV on the network and calculates the new network situation depending on the measurement results of PCCI RV and with a simulation of equivalent circuit (Fig. 3).

The situation becomes more complicated when the medium DER is installed into the network. In the third graph (Fig. 4, dotted lines) it can be seen how the network voltage profile would look like if there were no intervention (more than one third of users on feeder 1 have an inappropriate voltage value).

If the system reacted as in the previous case (OLTC reduces the initial value of the current), the users who are at the end of feeder 2 would have a lower voltage value as admissible. Here, we can see the most important value of the proposed concept. All the PCCIs which are installed across the feeder send the measured voltage values to the ACC control device. This device detects that the voltage of one PCCI is surpassed or unsurpassed and calculates new voltage parameters that would arise in the case of switching ratio in OLTC (the same as in the previous case). If these parameters were unacceptable, the device would find a ratio of OLTC which corresponds to the maximum value in the network and would calculate where the other feeder would drop out of the restricted limits (in our case is that PCCI PL). Then, this device finds the nearest PCCI (in our case PCCI RV) which has the proper value and disconnects feeder 2 from that point on. At the same time, PCCI PL sends decision to PCCI RV that it should connect the remaining feeder 2 into feeder 1. Now, all feeders have a suitable network-voltage profile at the expense of the feeder communication which was enabled by PCCI.

There is another case when the major DER or virtual power plant [8] is connected to the power network which causes that the network voltage profile exceeds tolerance limits.

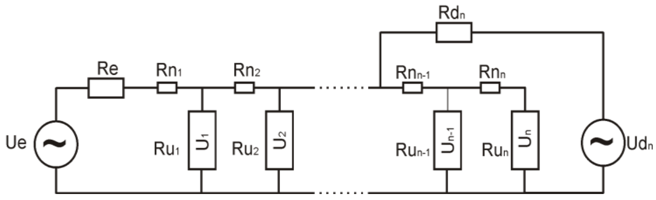

Fig. 3. Equivalent circuit for calculating a new situation in network

The system acts in the same way as it in the previous cases, however the control device cannot set the proper ratio on OLTC, so the control device decides to disconnect part of feeder 1. This decision of the OLTC control device is sent to the PCCI TP on feeder 2 which examines the possible solutions and calculates the new electrical parameters.

If DER on feeder 1 has enough power to supply part of the feeder, PCCI RV sends this information to PCCI TP which confirms this decision. This decision is also sent to PCCI SUB, which properly reacts and sends setting to OLTC. At the same time, PCCI RV disconnects the feeder and operates as a private or isolated power distribution network. If the voltage values were still outside the restricted limits, the PCCI RV would send this observation to the PCCI TP on feeder 1, which would disconnect the feeder from the primary distribution network and connect it back to the distribution network powered by DER. This disconnection and connection are realized by using of uninterruptible power supply (UPS) and the frequency synchronizers which ensure that switching is effected without any problem. Advantages of this concept and methodology are the improved surveillance over the distribution system, which consequently optimizes the network, particularly by reducing power reserves. The proposed concept also provides an updated structure of the power network clearing problems with the existing mounted DER.

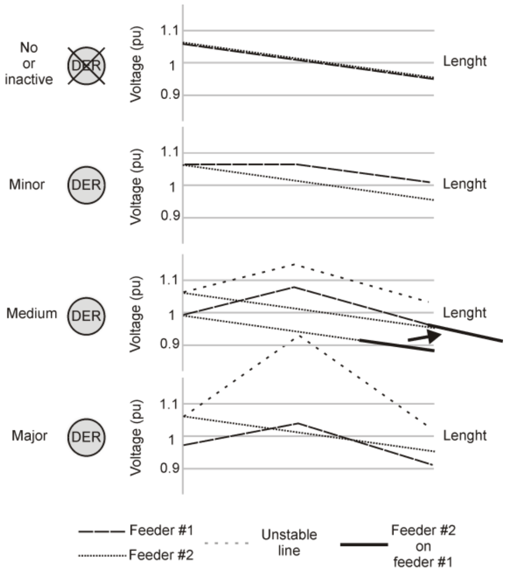

Fig. 4. Possible voltage profile according to the DER size

4 PCCI STRUCTURE

The proposed concept is presented with a prototyping system – PCCI, which consists of an appropriate hardware (Fig. 5) and software (Fig. 6) equipment.

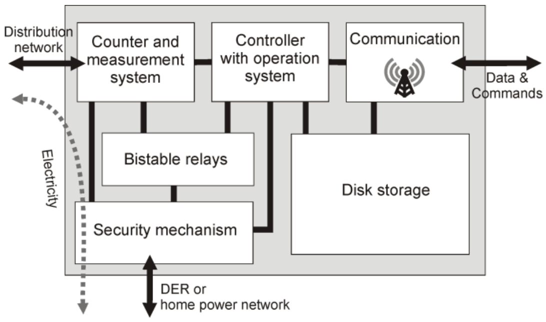

Fig. 5. PCCI hardware

In Fig. 5, the main hardware components of PCCI and interfaces between them are shown. The link between components is a controller which works on the Ubuntu (linux) operation system. This controller has programmable digital inputs and outputs used for determine operations of bistable relays. These relays can handle various tasks depending on the type of PCCI.

An important link, from the economic prospective, in the PCCI structure is the counter of the consumed or produced energy. This counter is upgraded in to a measurement system which can determine the electricity quality according to the SIST EN 50160 standard. All the obtained data are transferred via the controller to the disk (greater system reliability, data archiving…). Data are transferred to ACC and to end users over a communication module (Ethernet, GPRS or WiFi), which has direct access to the data stored on the disk, which can be accessed with an internet application. The communication between the VSM and the ACC is based on Ethernet, which uses a private network (PN) [9] or GPRS [10] based on the IEC 61850.

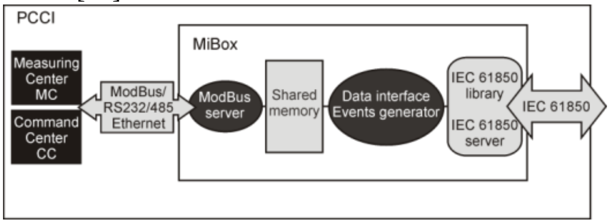

Fig. 6. PCCI software

In Fig. 6, the main components of the PCCI and interfaces between them are shown. Components are divided into two parts using a common shared memory. The first part of the software is responsible for collecting measurements from MC and sending commands to CC. The second part of the software is the application which behaves as a traffic light and sorts data according to the type of PCCI (ACC, PCCI TS, PCCI DER, PCCI USR, and PCCI SUB). When the data is properly classified, the application encodes the data into the type which is required for the IEC 61850 standard and then it sends it to the pre-defined recipients.

5 INTEGRATION INTO THE IEC 61850STANDARD

To raise the feasibility of the system, it has to be integrated with one of the existing standards. IEC 61850 [11] is the standard for the power industry and is becoming the protocol of choice as utilities migrate to network solution for substations and beyond [12].

The IEC 61850-7-420 [13] standard is composed of a number of predefined logical nodes which control their area. This standard is relatively new and it does not cover all the possibilities that a modern power network is capable of. One of the missing logical nodes (LN) is the logical node used, for controlling the network voltage profile. Therefore, in this paper we propose to establish a new LN which supports the controlling network voltage profile in the power network [14], it is called Voltage Profile LN (VP LN).

In Table 1, presentation of the VP LN class logical note is shown. This LN contains all the information that is required for controlling the network voltage profile of an electric power network. One of the special features of this LN is its high activation priority which can be turned on or off with an alarm trigger.

This concept of integration of new LN into IEC 61850 brings another idea which now will not be discussed. There is already a standard which defines communication between substations (IEC 61850-90-1) and between the control center and substation (IEC 61850-90-2). Therefor is missing only part which deals with the end-user and determines LN and communication between them. With the introduction of the remaining IEC 61850 standards, the family of standards will cover the entire energy sector, which should lead to simplification of communication in the distribution power network.

Table 1: Proposed logical node (SCP Class)

SCP class		
DATA Class	Attr.Type	Explanation
Common Logical Node Information		
	LN shall inherit all Mandatory Data from Common Logical Node Class	
System information		
SupStat	SPS	Superior station
NumStat	SPS	Number of stations in system
Status information		
AuProAvail	SPS	Auto-protection available
PLPAva	SPS	Power line protection available
DERAva	SPS	DER protection available
NumDNet	SPS	Number of DER in network
Location information		
DEROn	SPS	Manage DER
PLOn	SPS	Manage power line
PLNum	SPS	Power line number
SeNumDER	SPS	Serial number of DER (only for substation with DER)
Measured values		
A	WYE	Phase current (IL1, IL2, IL3)
U	WYE	Phase voltage (U1,U2,U3)
W	WYE	Phase active power (P1,P2,P3)
Protection Commands		
ActDER	SPC	Activate DER
DeActDER	SPC	Deactivate DER
ActPL	SPC	Activate power line
DeActPL	SPC	Deactivate power line
Alarms information		
Aon	SPS	Alarm is activated
Aoff	SPS	Alarm is deactivated
Aover	WYE	Exceeded value of current
Asig	SPC	Sign of the exceeded value
ANum	SPS	Which substation has first spotted alarm
↑ Data Name	↑ Common Data Class	

6 Conclusion

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

This situation is solvable by using electrical and communication mechanisms which form the framework of ICI. With this network several benefits can be obtained such as supervision of the distribution network and access for all users to internet application where the user can monitor power consumption and specifies his settings.

In this paper, a concept of communication mechanism to be used for controlling the network voltage profile and detecting problems which may appear in the distribution network with DER is presented. One of the special benefits of a concept is the possibility of integration into existing IEC 61850 standard.

Our future work will focus on moving the concept from the control area to a real power distribution network with several DERs and to extending logical nodes in the IEC 61850 standard, which will solve problems arising with introduction of DER.

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