CHANGING NETWORK CONDITIONS DUE TO DISTRIBUTED GENERATION – SYSTEMATIC REVIEW AND ANALYSIS OF THEIR IMPACTS ON PROTECTION, CONTROL AND COMMUNICATION SYSTEMS

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ABSTRACT

The development of distributed generation in power systems causes manifold changes due to the network performance and system behavior. Until now numerous papers are dealing with this topic, but considering only partial aspects of these issues. A systematical approach which is particularly necessary in nowadays complex networks and a coherent analysis of impacts is still missing. This present paper is pointing out a proper approach getting holistic results for this matter. Hence a systematical review on the general impacts of DGs on power systems will be presented. Based on that, this paper is analyzing and discussing exemplary impacts on protection, control and communication systems.

INTRODUCTION

Distributed generation (DG) is going to characterize the power systems worldwide. It causes drastic structural changes in the power systems on distribution level in particular. These changes have a physical as well as a technical character and will impact the steady-state and transient network behavior under normal or faulty network conditions [1], [2].

Protection systems as an indispensable part of the power systems are impacted consequently. Because of the high importance of protection systems as well as communication and control their proper function must be also ensured under these new network conditions [3], [4].

Thus the changing network conditions pose new challenges for the grid protection, control and communication systems. Nowadays only partial solutions are available which do not consider the grid and the protection as one system unit. Systematic and holistic investigations of new protection and control methods and concepts are necessary, but have been done quite rarely until now.

This paper presents a systematic review and analysis of the changing network conditions and their impacts on protection, control and communication systems due to the utilisation of DG. It shows the necessity to consider the grid and the protection system as one unit to satisfy the requirements on protection like speed, sensitivity and selectivity.

These systematic and holistic investigations are based on an expanded literature research of state-of-the-art, a structuring and conditioning of the impacts and challenges and DG-network simulations for verification. Figure 1 illustrates this approach. The acquired knowledge builds a necessary fundament for developing new methods and concepts for the protection, control and communication systems which are required in future DG networks.

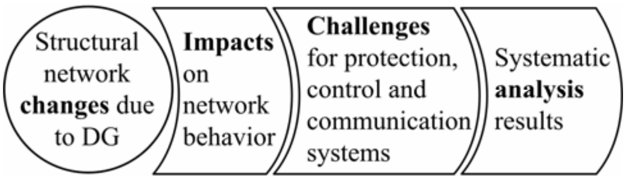


Fig. 1. Flow-chart of the systematic approach

CLASSIFICATIONS

To achieve a systematic overview of the different impacts and challenges, an adequate classification must be found. First of all, the impacts will be distinguished which are characterized to be **local or global**. Local impacts become effective only within one sub-network (e.g. network of a public utility company). Global impacts are classified as phenomena which affect the interactions between different sub-networks in contrast (see Fig. 2).

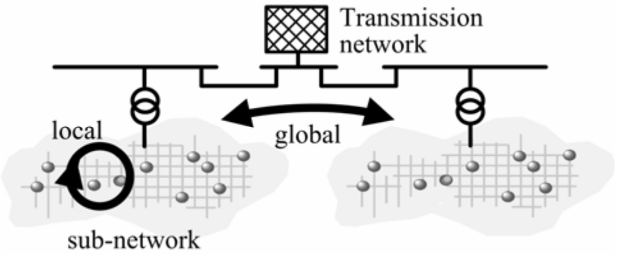


Fig. 2. Illustration of local and global impacts

One impact, e.g. the intermittent short-circuit (sc) power, could have local and global impacts. Thus it is important to mention to which regard the impact should be discussed. The attitude local or global impact on the network is determining decisively the influence on further network devices like e.g. protection and the challenges and solutions to overcome these impacts.

Two in principle different domains of network behavior are **steady-state and transient**. Steady-state means in this case that the time depending signals of current or voltage in the range of milliseconds and below are not considered. Thus the impacts are also classified into such structure preferably. Thirdly protection, control and communication systems are

made up of the six following subunits:
SENSing: The behavior of transducers like current- or potential transformers under steady-state and transient conditions. **PICK-up:** The pick-up unit distinguishes between normal load and fault conditions. **PROCessing:** Evaluation of the measured quantities regarding magnitude, phase angle, etc. based on that the tripping decision has to be made. **COORdination:** For a selective, sensitive, and reliable protection system, the protection relays must be coordinated, e.g. graded, with each other. **COMmunication**: Communication links between protection devices used for teleprotection. **CONtrol**: General item for all tasks regarding regulation, supervision, communication and coordination of non-protective devices.

STRUCTURAL NETWORK CHANGES AND IMPACTS ON THE NETWORK BEHAVIOR (TABLE 1)

Table 1 structures the general network changes and their impacts on the network behavior. According to our approach of Fig. 1, Table 1 is read from left to right as the items **A**, **B** and **C** on the left are the structural network changes due to DG and rightwards are listed the associated impacts on the **s**teady-state and **t**ransient network behavior. The classification into local and global impacts is done by round marks. Firstly the mentioned impacts do not underlie any aspects of protection, communication or control as they can be the general basis for other studies, too.

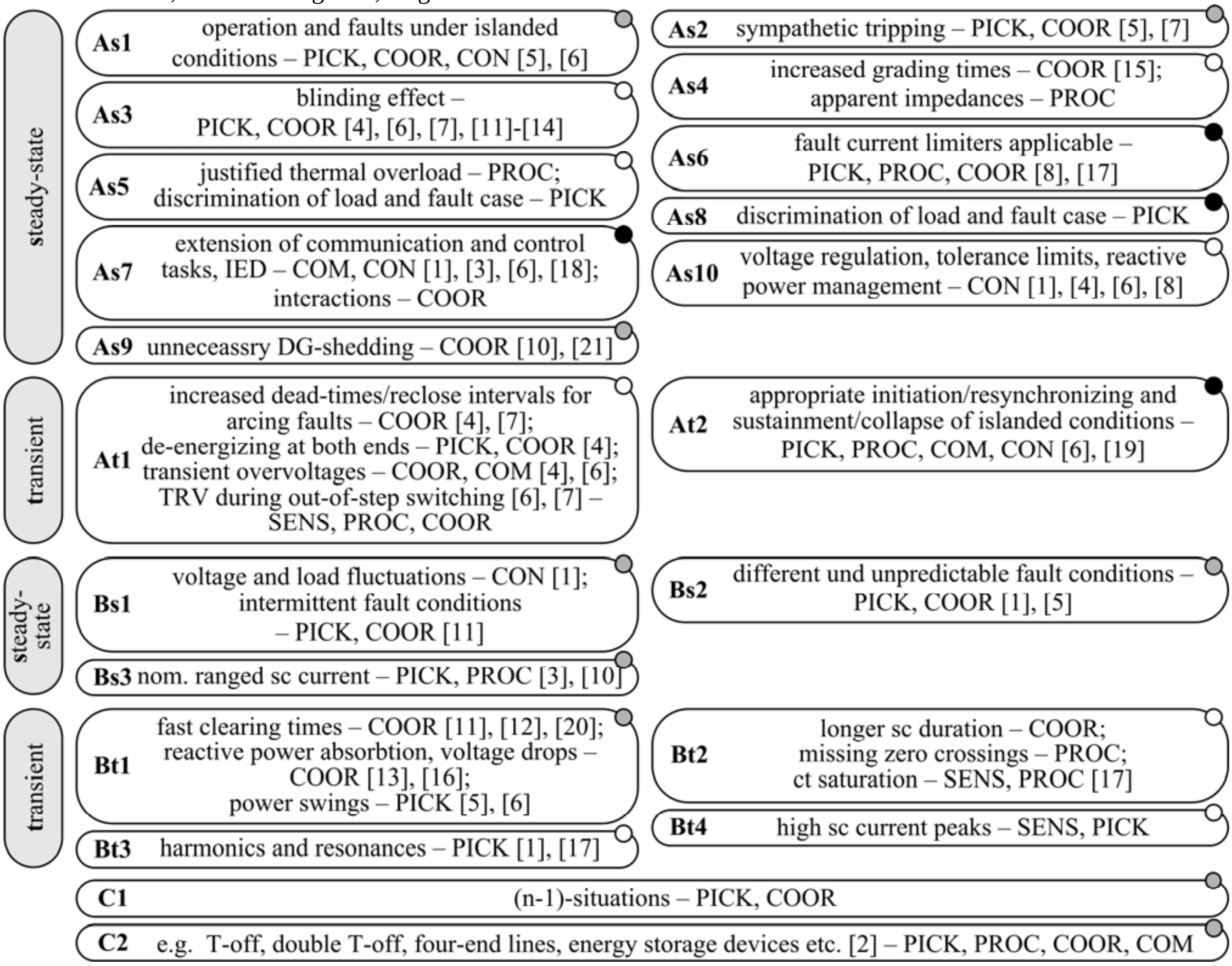
NEW CHALLENGES ON PROTECTION, CONTROL AND COMMUNICATION SYSTEMS (TABLE 2)

Based on the impacts on the network behavior the new challenges for protection, control and communication systems can be derived. Table 2 structures the challenges in correspondence to Table 1, that is the challenge **As6** - fault current limiters applicable - in Table 2 derives from impact **As6** - unpermissible increase of sc power - in Table 1, for example.
Additionally it is analyzed which subunit is affected (SENS, PICK, PROC, COOR, COM and CON). E.g. Bt3 - harmonics and resonances - due to operation of converter infeeds in parallel affects the pick-up of protection systems.

Table 1. Structural network changes and impacts on steady-state and transient network behavior due to DG
○ local, ◍ local and global, ● global

A Infeeding nodes connected to DG units everywhere in the network	**s**teady-state	**As1** islanded network operation [1], [5], [6] ◍	**As2** bidirectional power flow in the positive-/zero sequence system [1], [3]-[12] ◍
		As3 interinfeeds in the positive-/zero sequence system [7], [11]-[14] ○	**As4** higher density of nodes/substations [15] ○
		As5 higher loadings of equipment [1], [16] ○	**As6** unpermissible increase of sc power, ampacity [5], [8], [17] ●
		As7 virtual power plants and energy management systems [1], [3], [18] ●	**As8** load flows for back-up or energy storage ●
		As9 unadapted connection conditions [10] ◍	**As10** inverse voltage profile [1], [8] ○
	trans.	**At1** reverse voltage during de-energizing [7], [9], [13] ○	**At2** islanding philosophies [6], [19] ●
B Diff. types, prim. energy sources, power ratings, power characteristics and connection technologies of DG units	steady-state	**Bs1** intermittent power infeed and sc power [1], [11], [16] ◍	**Bs2** different sc behavior due to amplitude and duration of the sc currents [1], [5] ◍
		Bs3 operation of converter infeeds in parallel [3], [10] ◍	
	transient	**Bt1** after-fault-recovery [7], [11]-[13], [16], [20] ◍	**Bt2** decaying AC- and higher DC-components [17] ○
		Bt3 operation of converter infeeds in parallel [1], [17] ○	**Bt4** sc characteristics of storage units [1], [18] ○
C Deviating from standards		**C1** neglecting of the (n-1)-principle ◍	
		C2 non conventional equipment, network configurations and philosophies [17] ◍	

Table 2. New challenges for protection, control and communication systems
○ local, ◍ local and global, ● global



	Item	Challenge	
steady-state	**As1**	operation and faults under islanded conditions – PICK, COOR, CON [5], [6]	◍
steady-state	**As2**	sympathetic tripping – PICK, COOR [5], [7]	◍
steady-state	**As3**	blinding effect – PICK, COOR [4], [6], [7], [11]-[14]	○
steady-state	**As4**	increased grading times – COOR [15]; apparent impedances – PROC	○
steady-state	**As5**	justified thermal overload – PROC; discrimination of load and fault case – PICK	○
steady-state	**As6**	fault current limiters applicable – PICK, PROC, COOR [8], [17]	●
steady-state	**As7**	extension of communication and control tasks, IED – COM, CON [1], [3], [6], [18]; interactions – COOR	●
steady-state	**As8**	discrimination of load and fault case – PICK	●
steady-state	**As9**	unneceassry DG-shedding – COOR [10], [21]	◍
steady-state	**As10**	voltage regulation, tolerance limits, reactive power management – CON [1], [4], [6], [8]	○
transient	**At1**	increased dead-times/reclose intervals for arcing faults – COOR [4], [7]; de-energizing at both ends – PICK, COOR [4]; transient overvoltages – COOR, COM [4], [6]; TRV during out-of-step switching [6], [7] – SENS, PROC, COOR	○
transient	**At2**	appropriate initiation/resynchronizing and sustainment/collapse of islanded conditions – PICK, PROC, COM, CON [6], [19]	●
steady-state	**Bs1**	voltage and load fluctuations – CON [1]; intermittent fault conditions – PICK, COOR [11]	◍
steady-state	**Bs2**	different und unpredictable fault conditions – PICK, COOR [1], [5]	◍
steady-state	**Bs3**	nom. ranged sc current – PICK, PROC [3], [10]	◍
transient	**Bt1**	fast clearing times – COOR [11], [12], [20]; reactive power absorbtion, voltage drops – COOR [13], [16]; power swings – PICK [5], [6]	◍
transient	**Bt2**	longer sc duration – COOR; missing zero crossings – PROC; ct saturation – SENS, PROC [17]	○
transient	**Bt3**	harmonics and resonances – PICK [1], [17]	○
transient	**Bt4**	high sc current peaks – SENS, PICK	○
	C1	(n-1)-situations – PICK, COOR	◍
	C2	e.g. T-off, double T-off, four-end lines, energy storage devices etc. [2] – PICK, PROC, COOR, COM	◍

SYSTEMATIC ANALYSIS RESULTS

Only the investigations on sub-networks and the protection system as one unit affort systematic analysis of interdependencies between the challenges for protection, control and communication systems. E.g. a well-known problem: As2 - sympathetic tripping - interacts contrarily with As3 - blinding-effect - in the manner that sympathetic tripping may require higher pick-up values unlike blinding lower pick-up values [7]. Anymore Bt1 and Bt2 or As4 are contrary requiring fast clearing times (Bt1) and longer sc duration (Bt2, As4). On the other hand the challenge As2 - sympathetic tripping - is no problem if only the change Bs3 - operation of converter infeed - takes place. These consideration can be further continued.

CASE STUDIES

Because of the shortage of space it is impossible to present case studies for all items in Table 1 and 2. As one example the case in Fig. 3, discussing As2 – sympathetic tripping - is shown.

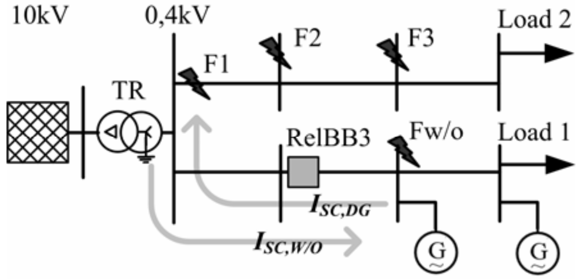


Fig. 3: The investigated MV/LV sub-network

Figure 3 represents a sub-network consisting of a public 10kV-grid, one MV/LV transformer (TR), six LV-lines, two loads and two DG units (synchronous-type). Transmission capacity at the low voltage cable is 750kVA. The voltage profile does not exceed 10% due to EN 50160. Simulations were done to examine the sensed sc current I_{SC} of the relay “RelBB3” for:

1) Maximum condition: sc calculations considering three-phase faults at the locations F1, F2 and F3 with DG units ($I_{SC,DG,MAX}$) and at the location Fw/o without DG units ($I_{SC,W/O,MAX}$) connected; sc power $S_{SC,GRID}$ = 200MVA.

2) Minimum condition: sc calculations considering two phase fault w/o earth connection at the locations F1, F2 and F3 with DG units ($I_{SC,DG,MIN}$) and at the location Fw/o without DG units ($I_{SC,W/O,MIN}$) connected; sc power $S_{SC,GRID}$ = 50MVA.

Figure 4 shows the results as to be the ratio of $I_{SC,DG}/I_{SC,W/O}$. By the worst case (F1, minimum condition) the up-stream sc current reaches 89.6% from $I_{SC,W/O,MIN}$. This causes an unselective, sympathetic tripping for fuses and undirectional overcurrent relays. The effect becomes less with increased fault distance on feeder without DG connected.

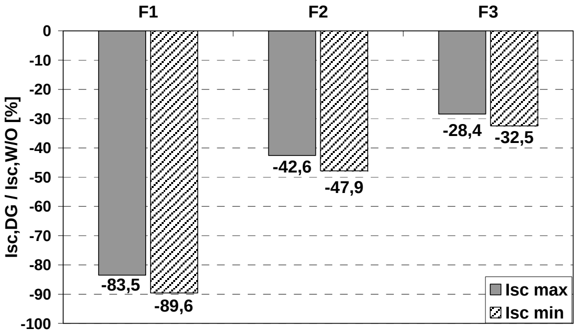


Fig. 4: I_{SC} in presence of DG for three different fault situations (F1, F2 and F3) detected at "RelBB3" (s. Fig. 3). $I_{SC,DG}$ is related to the $I_{SC,W/O}$.

CONCLUSIONS

This paper lists the impacts of DG units on the network behavior in general and derives the new challenges for protection, control and communication systems in a structured and coherent way. Sub-networks and protection system are considered as one unit. Interdependencies of the impacts and the consequences for new protection concepts can be only found in that way. Hence this paper is providing an appropriate and necessary base for developing new concepts for protection, communication and control as it will be the task in the future.

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