

## LOCAL INTELLIGENT CIRCUIT BREAKERS – A NEW CONCEPT FOR THE REFURBISHMENT OF EXISTING DISTRIBUTION NETWORK

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### ABSTRACT

*This publication presents an innovative solution proposal for the utilization of local intelligence in concept for circuit breakers. The concept covers the increasing technical demand to a meshed distribution network caused by volatile local generation of energy, especially renewable energy, and the non-synchronized energy demand by consumers, the future smart grid prosumers.*

### INTRODUCTION

The future of the European Electricity market was described in the „European Research Agenda for Europe’s Electricity Network of the Future“ [1] by the EU. The volume of the necessary investments into the distribution grid (DG) is estimated to 300 B€ over the next 30 years. These investments will cover only a smaller portion for so called Greenfield approaches. The majority of the investment will cover the refurbishment and extension of the existing infrastructure. The requirement will be the seamless integration of conventional energy generation, decentralised generation, renewable bulk generation (PV, wind, biomass, geothermic) at the transmission as well at the distribution level. To implement that into today’s hierarchical distribution grid, we have to anticipate the technical limitations in terms of the bidirectional power flow and the limited information flow. As a starting point today’s state of the art components like disconnecting switches and circuit breakers are discussed for their specific behaviour under these grid conditions, especially for the case of bi-directional power flow. Based on these results, a concept of the integration of local intelligence for the adaptive load management in future smart distribution grids will be introduced. As a core technology an intelligent Circuit Breaker (iCB) will be presented. By sensing the specific local network conditions and with the knowledge of the intrinsic physical status and performance of the iCB itself, critical network conditions (failures, dips, and short circuits) can be identified. In case of a short circuit or over-current situation the local load flow (energy level and direction) will be detected and the iCB will execute an adequate operation.

To show the transient behaviour during failure handling, a typical reference segment of a DG with bulk generation in-

feed as well as distributed renewable generation was defined. For this grid segment different switching operations and the dynamic network conditions were modelled. In a second scenario new concepts for the ultrafast isolation of failed grid segments by iCBs are presented, guaranteeing the unaffected operation of the healthy part of the DG.

### FUTURE NETWORK REQUIREMENTS

Today’s scheme of the distribution grid is characterised by a top-down unidirectional power flow from the power plant via the transmission to the distribution grid (Fig. 1 a). With the increasing volume of decentralised power generation at the low voltage and medium voltage level, the power flow becomes bi-directional (Fig. 1 b). This requires a new network management concept.

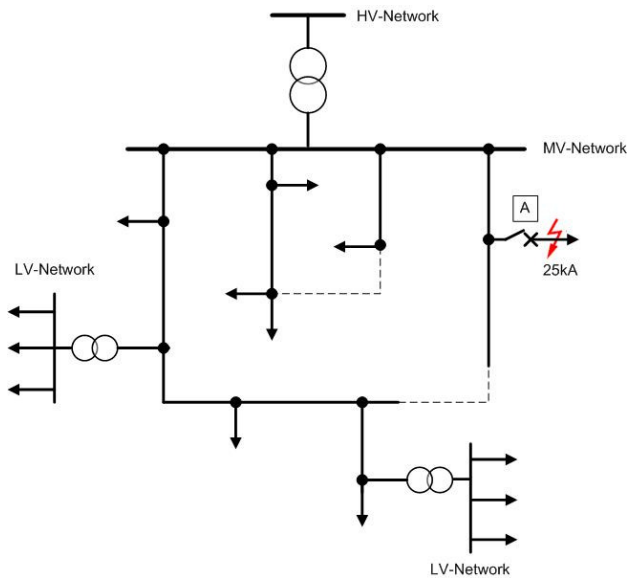
Basic limitations might be given by the capacity of cables and overhead lines, nevertheless the stability of the distribution will be a major concern. All decentralised generation will increase the short-circuit power in the grid segment, as a centralized generation management system is only applicable for bulk generation.

Having in mind conventional load break switches and disconnectors using the conventional physical principle of the arc-elongation by increasing the dielectric distance between the electrodes, a bi-directional power flow is not fully covered. These switches have a preferred power flow direction for the type-tested maximum switching current. Applying the reverse power flow, the maximum switching current might not be reached due to the electromagnetic forces to the arc. In today’s networks load break switches are successfully applied in ring architectures. Here an operation at maximum limit of the switching current will not appear. Otherwise, a GIS-RMU is used instead of a load break switch. Concepts like the iCB will deliver a unique solution for the increase of the grid stability without scrapping all existing infrastructure.

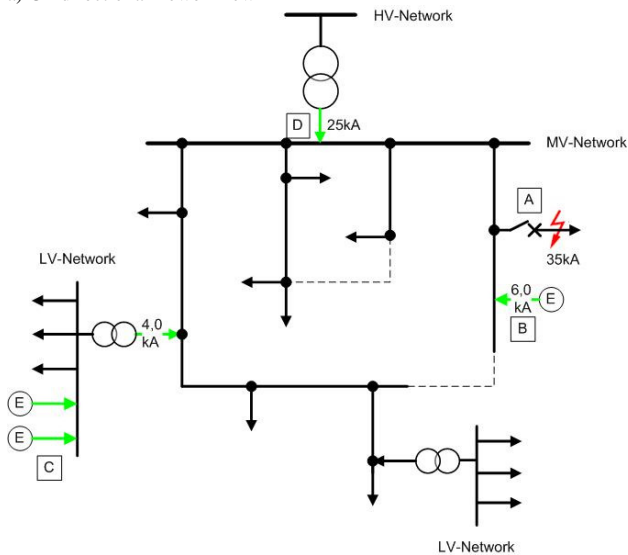
Fig. 1 shows a typical grid structure. The maximum short circuit current based on central generation equals to 25 kA. The breaker A has maximum  $I_{SC}$  of 31,5 kA. In case of local generation on the LV and MV grid, the maximum  $I_{SC}$  in the grid segment can reach 35 kA, what is clearly above the capability of breaker A.

**Table 1:** Dedication of Circuit Breakers in the Reference Grid (Fig. 1)

ID	Grid level	Type	Function
A	MV	iCB	Feeder
B	MV	iCB	Local Incomer
C	LV	iCB	Local Incomer
D	MV	Conv. CB / iCB	Central Incomer



a) Unidirectional Power Flow



b) Bi-directional Power Flow

**Fig. 1:** Reference Networks

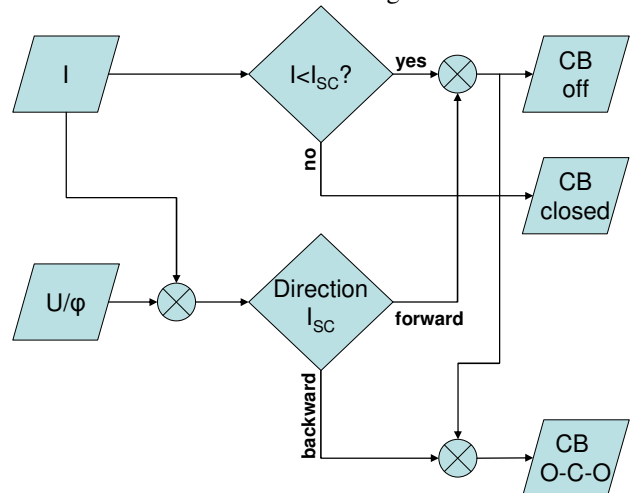
**CONCEPT OF A LOCAL INTELLIGENT CIRCUIT BREAKER**

The concept is distinguished by the local intelligence of the circuit breaker. The knowledge of his maximum current breaking capability and the real-time situation of his own grid condition are integrated into the iCB logic function. This can be covered by current sensing in combination with scanning the voltage or the phase condition of the current,

so that it is possible to derive the current and its direction. In case of a failure current, the closest breaker to the failure location will identify the failure and will decide upon its capability to handle the failure current. If the answer is yes, and the failure location is upstream, the breaker will switch off (Fig. 1, breaker A). In case that the failure is downstream the breaker will do an O-C-O sequence.

Due to local generation (Fig.1 b)  $I_{SC}$  might be above the physical capability of the breaker. Then the breaker will not operate and keep closed. This failure will also lead to a different power flow through the breaker B. As B is connecting local generation, this breaker can disconnect this additional generation. Doing so, the  $I_{SC}$  for breaker A will be now on a level where the failed line can be cleared. Breaker B will detect that the failure is cleared and can now reconnect the local generation.

In case of highly meshed grids the decision algorithms for the decentralised generation (breaker B) might not be explicit enough. Here the proposed solution would be the utilization of an iCB for the centralised generation connection, breaker D. In case of an failure current, breaker D will execute a synchronised O-C sequence, with capability for a final opening. So breaker A will see the first opening of D, will disconnect the failed line and the grid segment will be still online in case of a fast reclosing of breaker D.



**Fig. 2:** Decision Tree for an iCB

This concept is asking for the following requirements of the grid components: protection relays with over current and direction sensing, iCBs with operation time not influencing relay cascading, iCBs with higher peak withstand current than the maximum breaking current  $I_{sc}$ , i.e. with higher dynamic forces resistance.

The target of the standard concept is a fast execution of the operation, so that the time cascades of the conventional upstream grid is not influenced. As ideal reaction time for the DG, less than 100 ms are assumed, therefore the iCB must execute on opening operation in less than 30 ms (Fig. 3). The necessary requirements on the data acquisition and the breaker are: detection time of <10 ms and a resolu-

tion of 500 S/s to estimate the peak value, drive reaction time of 5 ms, maximum arcing time of 15 ms. In case of usage of power electronic switching devices, current zero switching is preferred and will lead to much higher requirements on the data acquisition and processing.

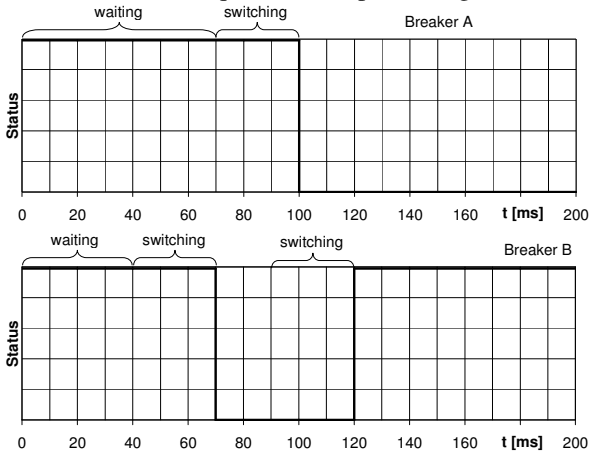


Fig. 3: Time schedule of an iCB for standard operation

### OPERATING REQUIREMENTS

In case of recognition a failure by the iCB, the direction of of the power flow is of high importance. With the assumption that all iCB have nearly the same operating time, the iCB detecting a downstream failure current should open first. In case of an upstream failure current, only breaker acting as a local incomer will operate, as the definitive clearing of upstream failures will be done in the upstream grid structure.

As a decision criterion the absolute value of the time dependent current  $|di/dt|$  is suitable, as for current zero this value will have a maximum. In case of a short circuit in an inductive network, the current will be superimposed by an exponential declining direct current. Therefore current zero can not be the criteria. As a new criterion the zero point of current curvature is taken:  $d^2i/dt^2$ . For  $d^2i/dt^2 = 0$  the momentary value of the direct current component can be derived. In case that the failure current is to high, the breaking capability of the iCB can be proven at every zero crossing of  $d^2i/dt^2$ . The amplitude of the steady state  $I_{SC}$  is given by:

$$|i_0| = \sqrt{2} \cdot |i_{SC}| \tag{1}$$

For  $\frac{d^2i}{dt^2} = 0$  and  $i \cdot \frac{di}{dt} > 0$  (2)

the neglected decaying DC-component is derived:

$$i_{dc} \approx \frac{di}{dt} \cdot \frac{1}{\omega} \tag{3}$$

The next maximum ISC is calculated to:

$$|i| < |i_0| + |i_{dc}| \tag{4}$$

If  $\frac{d^2i}{dt^2} = 0$  and  $i \cdot \frac{di}{dt} < 0$  (5)

then it is valid:  $i_{dc} = i$  (6)

and the next extrema of the  $I_{SC}$  is a local minimum with:

$$|i| > |i_0| - |i_{dc}| \tag{7}$$

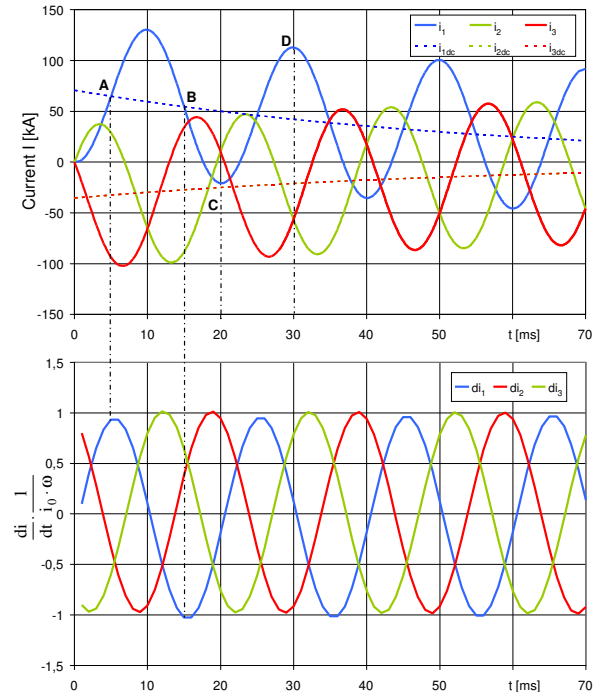


Fig. 4: 3-phase  $I_{SC}$ , DC-component  $i_{dc}$  and normalised amplitude of  $I_{SC}$

At Fig. 4, point A, the decision for the interruption is positive due to the phasing of the rising  $I_{SC}$  (2). For a system frequency of 50 Hz the next maximum will appear 5 ms after  $d^2i/dt^2 = 0$ . With a relay time delay of 10 ms and an inherent delay of 5 ms, the arc would ignite at the local minimum at point C (7). The next current zero happens a few ms later. Therefore it has to be anticipated that the TRV is sufficient for a re-ignition of the arc and therefore a final current interruption will happen 10 ms later. The arcing time will more than 10 ms.

In case the decision is taken at point B (5), the contact separation will happen at the current maximum at point D. The final current interruption will happen at next current zero at less than 10 ms, a scenario preferred for inductive networks.

### APPLICATION OF AN iCB

The basic discussion must be around the conditions to combine conventional switches or breakers and iCBs. Assuming that the local generation will lead in superposition with the central incomer a short circuit current above 25 kA (Fig. 1b) and with conventional switching times of today's vacuum CBs of 70 ms [2], the time cascading of the different CBs are described in Fig. 5. The effect of this switching sequence to the  $I_{SC}$  through the breaker A was simulated in ATP-EMTP and is shown in the Fig. 6.

In case of a failure downstream of breaker A, this breaker will find that he can not handle the failure current. Breaker

A is waiting until breaker B and C have detected the failure as well and have disconnected the incomers of the distributed local generation. The drop of the failure current will be detected by breaker A and this breaker will clear the failure. Finally breakers B and C will reconnect the local generation.

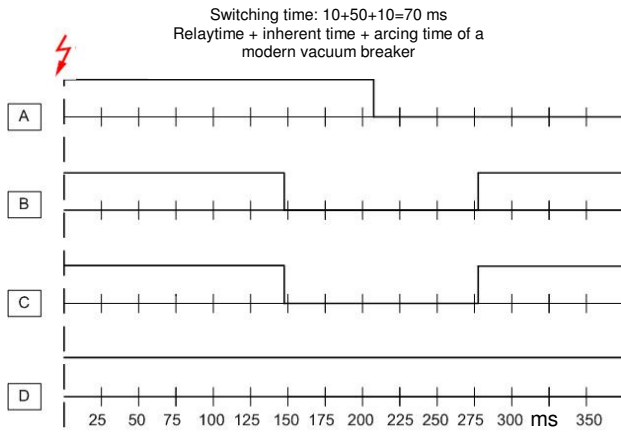


Fig. 5: Cascading of CBs with a switching time of 70 ms

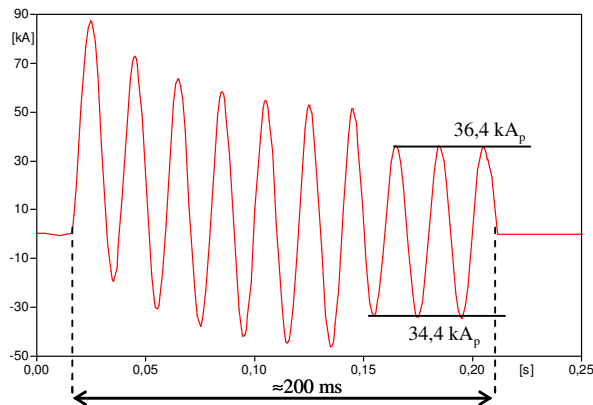


Fig. 6: Current I at breaker A, with turning off breaker B and C with switching time of 70 ms

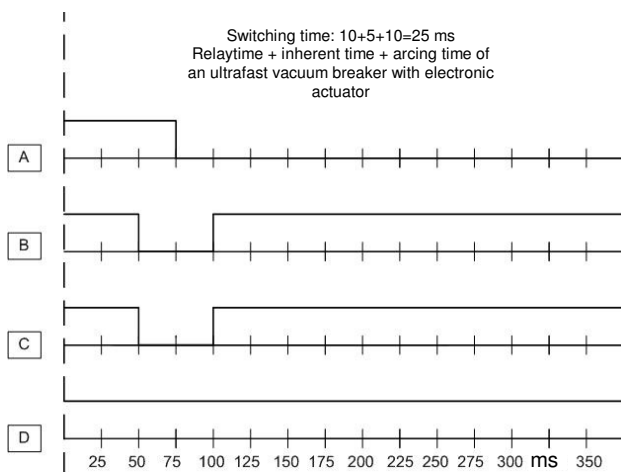


Fig. 7: Cascading of CBs with a switching time of 25 ms

Based on first analyses of larger structures of DGs, clear signals of complex transient balancing processes were

found. Thus transients can be reduced by shortening the switching time of the CBs to 5ms. This switching time can be achieved by electronically controlled actuators. The time cascades for these conditions can be found in Fig. 7 and the simulated current through breaker A in Fig. 8. The result shows that the iCB principle is still working under this conditions and a safe handling of the failure is possible.

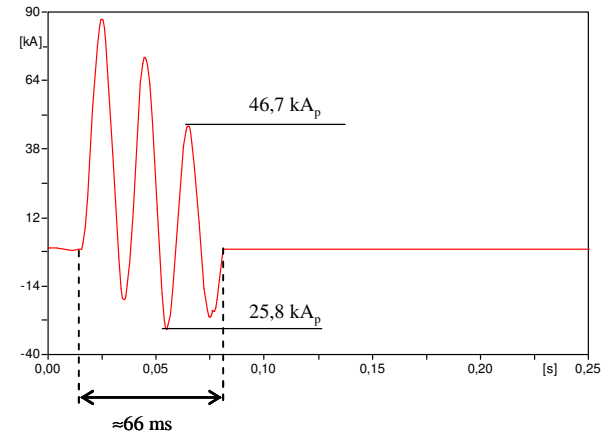


Fig 8: Current I at breaker A, with turning off breaker B and C with switching time of 25 ms

The simulation with both switching times clearly show, that although the iCB A has the short-circuit breaking capacity of 31,5kA, it must have higher peak withstand current. A standard IEC breaker is designed for 82kAp, in the simulated network the breaker must be capable for 88kAp.

CONCLUSION

With the iCB a possibility to upgrade existing distribution grid infrastructure towards Smarter Grid application is proposed, without implementing a new and exhaustive IT infrastructure. The iCB will be able to analyse the local grid status. In combination with the knowledge about its own switching capability, the iCB is able to identify, isolate and switch-off failures in a fast and safe way. It was shown, how an iCB has to be designed for distribution grids with decentralised renewable generation. Based on these requirements the behaviour of a reference grid was simulated for switching times of 70 and 25 ms of the iCBs. It could be shown that very fast switching times have advantages. The handling of the failure sequence at less than 100 ms will mean reduced short circuit energy and reduced transients in the grid segment. The transient behaviour of the iCB in larger and more complex grid structures will be crucial for utilization of the concept. Therefore extended studies will focus on transients in complex distribution grids.

REFERENCES

- [1] European Commission, *European Research Agenda for Europe's Electricity Network of the Future*, EUR 22580, Luxembourg
- [2] Fenski et. al., *Vacuum Interrupters*, etz, 2003