Novel approach to detect secondary arc on single pole tripping events

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***Abstract* — For single-line-to-ground faults on critical transmission lines, Single-pole tripping is sometimes utilized to avoid the negative impact of the "unnecessarily" three-phase tripping on power system transient stability. Single-pole tripping is normally followed by a single-pole automatic reclosing to restore the tripped phase and for non-permanent faults, the restoration is successful. However, occasionally, and due to the other two phases being energized, a secondary arc is formed rendering the single-pole reclosing attempt unsuccessful.**

To avoid such a failed reclosing attempt, and the need for a full three-phase trip and reclose with its dire consequences on the system stability, relay engineers set the dead time delay long enough to account for the typical secondary-arc extinguishing time in addition to some margin. The dead time delay is set based on prior experience with arcing faults on that specific line, or in the utility system where single-pole tripping is applied.

In this paper, a novel algorithm to detect secondary arc after single-pole tripping events is discussed. Further, case-studies where this algorithm has been applied are shown. Comparison between this new reclosing function and the traditional method is also provided.

The main benefit of applying this method is that, when there is no secondary arc, or when the secondary arc extinguishes relatively fast, a successful reclosing attempt is be made without the need to wait for the static dead time delay setting.

Implementing this adaptive approach would lead to fully harvest the benefits of using single-pole tripping since the restoration is achieved as soon as the secondary arc has extinguished leading to a more robust system.

Keywords – single pole tripping, secondary arc, automatic reclosing

I. INTRODUCTION

More than 75-80% of the single-phase fault events on the transmission or distribution lines are temporary and can be cleared if line is deenergized for some period of time to allow de-ionization. Such faults are typically caused by lightning strikes, swinging conductors during strong winds, or vegetation reaching too close to the conductors. Following the protection operation and fixed dead time, the conventional ANSI 79 autoreclose function performs automatic reclose attempt to restore the service on faulted line or line segment. In order to minimize the service interruptions and maintain system stability during the fault events, many utilities allow single pole tripping on the transmission lines. The isolated phase, however, maintains some potential induced by other two phases due to capacitive and inductive coupling. This potential could be high enough to support secondary arc at the fault location for prolonged period of time. Therefore, the dead time is typically applied using statistical data from the circuit including some safety margin to ensure secondary arc is extinguished. This paper discusses the autoreclose function with secondary arc detection which could dynamically change the dead time and reclose faster if secondary arch is extinguished.

II. CONVENTIONAL AUTORECLOSE OPERATION

During the fault event, the protection functions (for example distance element) operate the circuit breakers at both line ends. Protection trip triggers the 79 autoreclose function and initial deadtime for the first reclose attempt. After the deadtime the autoreclose function issues first reclose attempt and energize the line (Fig. 1). As soon as breaker closed, 79 function starts the reclaim timer, typically set for 30-60s. If no fault is detected during this time, the autoreclose attempt is considered being successful. If new fault occurs during reclaim time, protection operates the breaker and second autoreclose attempt is performed in order to reestablish the service.

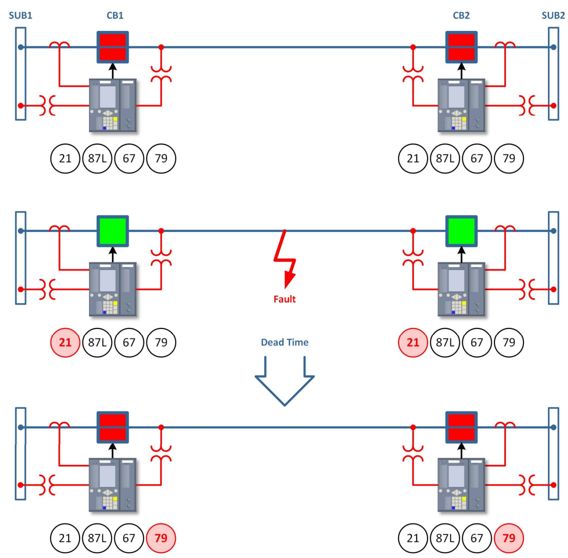

Fig. 1. Conventional autoreclose operation

III. WAYS TO IMPROVE AUTRECLOSE EFFICIENCY

Modern numerical relays have combined multiple protection and automation functions in one device. Analog measurements for all these functions are also available in the single processing environment, therefore more complex autoreclose algorithms can be accomplished:

- Decrease the dead time to minimum possible value;

- Allow single pole tripping and reclosing;
- Prevent reclosing onto a fault when broken conductor condition occurs;
- Implement secondary arc detection function.

The single pole operation can improve grid reliability and stability since customers can be supplied by unfaulted phases during the autoreclose dead times. In addition, protection scheme does not need to perform the synch check before single phase reclosing thus minimizing the total dead time.

The dead time of conventional autoreclose function can be decreased for the relay at one line end if voltage check is implemented. Fig. 2 illustrates the autoreclose with reduced dead time for circuit breaker CB2. Following a fault event, CB1

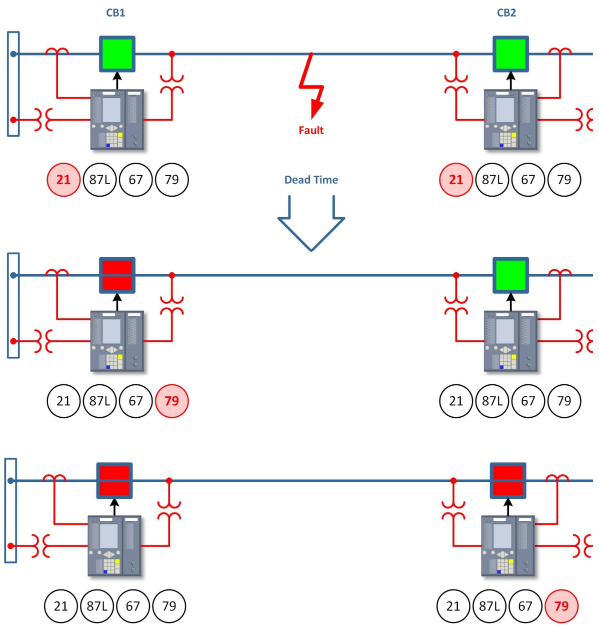

Fig. 2. CB2 autoreclose with reduced dead time

performs automatic successful reclose attempt after fixed dead time. Relay at CB2 measures healthy voltages in all 3 phases and can safely perform the reclose operation reducing the own fixed dead time. In order to implement this function, the potential transformers shall be available from the line side (bus side PTs are shown for 25 synch check function).

Another example of the autoreclose function with adaptive dead time is shown in Fig.3. When CB1 relay performs successful autoreclose, it can send the remote command to CB2 relay via IEC61850 GOOSE message or Protection Interface. This method

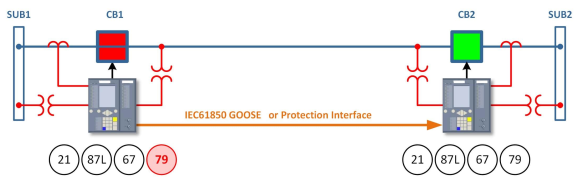

Fig. 3. Autoreclose with adaptive dead time

can be utilized if CB2 does not have PTs available on the line side.

IV. SECONDARY ARC

Following a single phase tripping, the voltage on the isolated phase is supported by two energized phases through capacitive and inductive coupling. This voltage can be high enough to support the secondary arc at the fault location for prolonged period of time. The equivalent circuit diagram is shown in Fig.4. The isolated

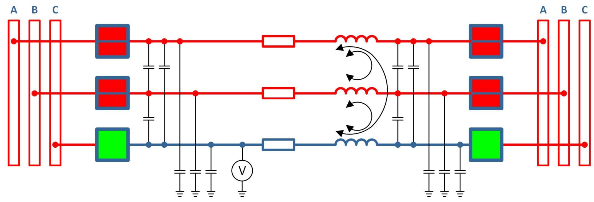

Fig. 4. Equivalent circuit

phase voltage can be measured by the protection relay to determine if secondary arc is present to adapt the dead time duration. In addition, the broken conductor or metallic fault condition can be identified if voltage magnitude is below certain value (typically 2%). In this case it is not a temporary fault and there is no need to perform an autoreclose attempt since it will not be successful. Typically a trip command shall be issued to all three phases to prevent unbalanced supply for prolonged period of time.

Fig. 5 depicts three stages of typical arcing fault:

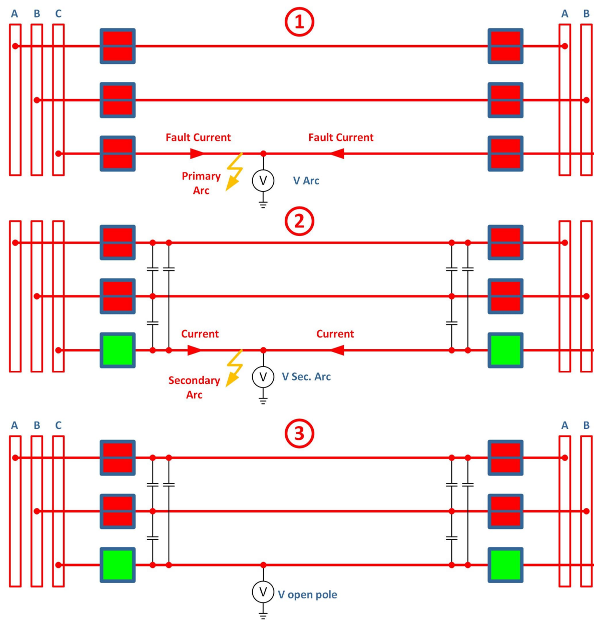

Fig. 5. Single phase arcing fault

- Stage 1 – The fault current is flowing through the circuit breakers and form the primary arc. Protection relays detect the fault condition and issue single pole trip at both ends to isolate the faulted phase.

- Stage 2 – Two energized phases support voltage on the isolated phase through capacitive and inductive coupling forming a secondary arc, which could be present for a second or longer.
- Stage 3 – Secondary arc has extinguished, the open phase voltage is pure sinewave with fundamental component.

V. SECONDARY ARC DETECTION

Following a single pole trip, relays measure voltage on the isolated phase and use the following criteria to detect the secondary arc:

- Content of 3rd, 5th and 7th harmonic caused by the non linear arc characteristics;
- Open phase voltage angle compare to the healthy phases;
- Amplitude of 3rd harmonic component in zero sequence voltage.

All three criteria are evaluated independently and weighted to

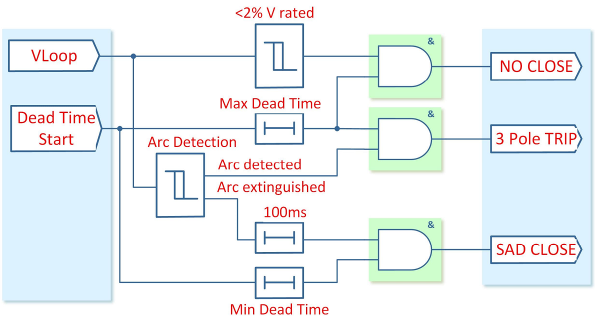

Fig. 6. Autoreclose function logic with secondary arc detection

make a final determination. Fig. 6 depicts the autoreclose function logic with secondary arc detection. Voltage VLoop from a faulted phase is compared to the nominal value to identify if it is a permanent bolted fault. If Vloop is less than 2% of the nominal voltage, no autoreclose attempt will be performed assuming the permanent fault. The arc detection algorithm has two outputs signaling if arc is detected or extinguished. If Maximum dead time is exceeded and arc is till present, the autoreclose function issues 3 pole trip command to extinguish the arc completely. Consequent autoreclose attempt can be issued to reestablish the service. If arc is extinguished, the autoreclose function waits for 100ms and verifies if the minimum required dead time has elapsed before issuing the close command.

VI. OPERATION EXAMPLES

The fault record from the fault event with no secondary arc is shown in Fig. 7. Following the protection operation (marker 2) the open phase voltage provide sinewave with fundamental component. No secondary arc is detected, autoreclose function waited for Minimum dead time and performed successful autoreclose attempt.

The secondary arc was detected during the fault event shown in Fig. 8. Device issued internal signal “Secondary arc detected”. The arcing time was approximately 180ms. Once arc has

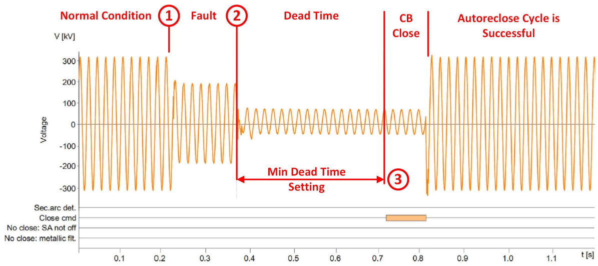

Fig. 7. Fault event with no secondary arc

extinguished (marker 3) function waited for 100ms (marker 4) but issued close command only when min dead time has elapsed (marker 5). In this example the arcing time was relatively short and did not exceed the minimum dead time value.

Another fault event with prolonged arcing time is shown in Fig.9. The arc was present for approximately 320ms (between markers 2

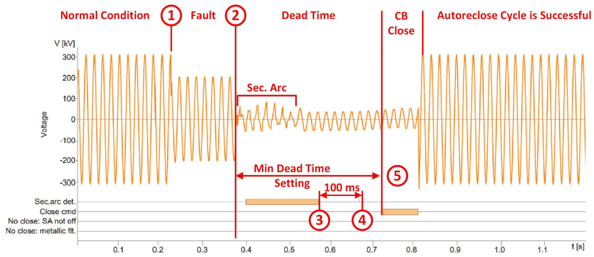

Fig. 8. Fault event with secondary arc

and 4) exceeding the minimum dead time value. Autoreclose performed successful reclose operation 100ms after arc has extinguished. The total dead time was automatically adjusted during this event.

Fig. 9. Fault event with secondary arc

VII. CONCLUSION

The secondary arc detection function improves single pole autoreclose performance. The dead time duration is automatically adjusted based on the secondary arc presence, therefore short average dead times can be achieved. Function prevents unnecessary reclosing onto a permanent fault reducing circuit breaker stress. Three phase trip is performed if secondary arc do not extinguish to improve chances of clearing the temporary faults. Implementing this adaptive approach would lead to fully harvest the benefits of using single-pole tripping improving the grid reliability.

VIII. REFERENCES

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