Sectioning of branches of distribution networks with connected wind power plants

J N Bakardjieva¹, M I Matsankov² and Svatoslav Slavov²
¹ Sectron, “G. M. Dimitrov” 52, Sofia, Bulgaria
² Technical University of Sofia, EPF-Sliven, “Bourgasko chose” 59, Sliven, Bulgaria

e-mail: mmisho.ivanov@abv.bg

Abstract. The paper presents a developed algorithm for coordinating the response times of the devices for automatic sectioning of bilaterally power supplied lines, of the digital relay protection and the reclosers in medium-voltage distribution networks with connected wind power plants.

Keywords: power distribution networks, wind power plants, sectioning, setting.

1. Introduction
The connection of wind power plants to a medium voltage (MV) electricity network creates bilaterally supplied sections [1]–[5]. In practice, parallel, series and parallel-series sectioning is used for two-way power supplied lines [6].

The main disadvantage of the parallel and series sectioning is the impossibility to supply a reserve feed to the undamaged section of the network in case of line damage. Therefore, a variant of automatic serial or serial-parallel sectioning of the lines with two-sided power supply using reclosers is applied [7,8,9]. Paper [10] presents the developed algorithms for coordinating the action of the means for relay protection (RP), the reclosers, the automatic reclosing (AR) and the automatic activation of the reserve (AAR).

The aim of this paper is to introduce an algorithm for coordinating the response times of the devices for automatic sectioning of branches with bilateral power supply.

2. Sectioning scheme of open branched distribution networks with connected decentralized energy source (DES)
The scheme for series sectioning of a bilaterally supplied section A₁-A₂ of the network is shown in Fig.1. One power source is the wind farm (G) and the other is the substation for connection to the electricity system (S). Some of the consumers (B₁, B₂) are connected to the bilaterally supplied section A₁-A₂. The consumers B₃÷B₁₀ remain unilaterally powered by the connection node A₃. In a normal mode, the sectioning device Q₃ is off.
**Figure 1.** Sectioning of an open branched distribution network with connected DES: Q1, Q2 - circuit breakers; sectioning device Q3; AAR - sectioning breaker with AAR in off position; $B_{1\Sigma}$, $B_{2\Sigma}$ - total electric loads to sections 1 and 2, obtained from the division of the bilaterally supplied section by means of the sectioning device Q3; S - electrical network; SS1 and SS2 - substations; B3+B10 - electric loads

3. **Sectioning scheme of bilaterally supplied lines**
The scheme for series sectioning of a two-sided supply line is shown in Fig.2. One power source is the wind farm and the other one is the S system. All consumers are connected to the bilaterally powered line.

**Figure 2.** Series sectioning of a line with bilateral power supply: SS - substation; Q1 - Q2 - circuit breakers; Q3 - sectioning breaker; AAR - sectioning breaker with AAR in off position; G - wind generator; S - electrical network; T1, T2 – transformers.

Series sectioning of a bilaterally supplied line with additional circuit breakers Q4 and Q5 is shown in Fig.3. With their automatic shutdown, the area of appearance of short circuits - k1 or k2 - on the bilaterally supplied line can be located.

**Figure 3.** Scheme of series sectioning of a line with bilateral power supply: SS - substation; Q1 - Q5 - circuit breakers; AAR - sectioning breaker with AAR in off position; G - wind generator; S - electrical network; T1, T2 – transformers.
Parallel sectioning of an open branched network with additional circuit breakers Q4, Q5 and Q6 is shown in Fig.4.

The scheme in Fig. 5 illustrates that either of the damaged sections can be switched off automatically on both sides and the damage can be localized, while the remaining sections will receive power from the other substation. The peculiarity of the scheme is the obligatory presence of a network AAR and directional protections of the sectioning devices, as power flows in two directions are possible.

4. High-speed reclosers in adaptive digital relay protection (DRP) circuits

In principle, the disconnection of a short circuit in high-voltage (HV) electrical networks is done with the help of circuit breakers, equipped with AR. In recent years, high-speed reclosers have been used in HV distribution networks, which are also used for accomplishing AR [7,8,9].

This allows for detection of short circuits, quick shutdown of the damaged area, reconnection and shutdown in case of permanent failure. In the case of a transient short circuit the power supply is restored without further disconnection. The first high-speed reconnection is without interlocking (i.e. without checking for voltages on both sides of the circuit breaker). The locks for the next automatic reconnection are controlled by the operating mode in the electrical network.

As the high-speed reconnection function does not check for the network conditions, reconnection is possible with an existing permanent short circuit. Thus, the generators, which are close to the short circuit, will be subjected to reloading caused by the reconnection. For this reason, a high-speed
adaptive reconnection circuit is desirable to test the voltages in the system before reconnecting and to block it if an existing fault is detected. This is recommended for reclosers mounted near a generator.

5. Coordination of the AR action for power lines with bilateral supply

The choice of the AR response time for a power line with double-sided power supply takes into account the settings for the disconnection times for the short circuit by the relay protection RP, mounted on the opposite end of the line.

The time delay of a single AR or the first cycle of a double AR on unilateral supply lines should meet the following three conditions [10,11]:

- the time delay \( t_{AR} \) of the AR must be greater than the standby time \( t_{react} \) for reactivation of the switching off circuit-breaker

\[
(1) \quad t_{AR} = t_{rea} + t_{res},
\]

where \( t_{rea} = 0.2 \pm 1 \) s; \( t_{res} = 0.3 \pm 0.5 \) s - the reserve time, taking into account the changeability of \( t_{rea} \);

- the time delay of the AR must be greater than the time for deionization of the medium

\[
(2) \quad t_{AR} = t_{d} + t_{res},
\]

where \( t_{d} = 0.1 \pm 0.3 \) s is the deionization time; \( t_{res} = 0.3 \pm 0.5 \) s – the reserve time, taking into account the scatterings of \( t_{d} \).

- the third condition for setting the time delay of the AR is determined by:

\[
(3) \quad t_{AR} = t_{d} + t_{rp2} + \Delta t_{rp2} + t_{c2} - t_{rp1} - t_{c1} + \Delta t_{rp1},
\]

where \( t_{rp1}, t_{rp2} \) is the response time of the second stage of the relay protection, respectively at its own and at the opposite end of the power line; \( \Delta t_{rp1}, \Delta t_{rp2} \) - the reserve, taking into account the deviation of the time delays of the RP, respectively at its own and at the opposite end of the line; \( t_{c1}, t_{c2} \) - the own time for actuation of the circuit breaker, respectively at its own and at the opposite end of the line; \( t_{d} \) - the time for deionization of the medium.

The higher of the obtained values of \( t_{AR} \) is taken for accomplishing the process of setting.

If the second stage of protection does not provide sufficient reliability in case of a short circuit at the end of the line (the sensitivity factor is below \( 1.3 \pm 1.4 \)), in expression (4) the time delay of the third stage of protection is added.

When installing reclosers in the schemes, presented in Fig.3 ÷ 5, the setting of the AR for each of the reclosers takes into account the settings of the RP and AR of the two adjacent switching devices (breakers and reclosers).

6. Calculation of the settings for the response times of directional protection for a circuit with bilateral power supply (Figure 6)

The selected time delays of the individual protections do not contradict to each other. The protection system is feasible.
Figure 6. Response times of directional protection for a bilaterally supplied circuit.

7. Setting of the response times for automatic activation of the reserve power supply

The devices of RP, reclosers, circuit breakers and AAR all work together in the bilaterally supplied section of the electrical network (Fig. 7).

The setting of the response times of the switching devices is in accordance with the sequence of their operation:

- In case of a short circuit in point K, the nearest recloser R1 turns off;
- The AR on recloser R1 starts operating and in case of a transient short circuit, the normal operation is restored;
- In case of unsuccessful AR, all reclosers near the AR point switch off at the same time (in this case R2 and P3). When they are off, an impulse is given to change the direction of their protection.
- After the voltage disappears at the AAR point, its circuit breaker is switched on from the side of S1.
- The recloser R3 is switched on and the fault is located in the area between R1 and R2.

Figure 7. Coordination of the circuit breakers and reclosers operation in a bilaterally power supplied network: Q1, Q2 - circuit breakers; R1 ÷ R5 - reclosers; AAR - automatic activation of the reserve.

The main settings of the AAR are: control of the voltage of the adjacent section and of the response time of the AAR. The voltage control setting of the adjacent section must be at a level of not less than 0.9 U_nom, in order to ensure reliable starting of the electric motors of the switched off section.
8. Determination of the time settings for the AAR and the reclosers in branches with bilateral power supply

Fig. 8 shows a diagram of branches of an electrical network with bilateral power supply, AAR and reclosers.

![Diagram of an electrical network with two-sided power supply, AAR and reclosers.](image)

**Figure 8.** Scheme of an electrical network with two-sided power supply, AAR and reclosers.

The sequence of actions consists in the following:

- The number n of the reclosers in each branch is entered.
- The setting parameters for a case with a short circuit in section 1 are determined. The response time for the AR, \( t_{ARQ1}^{off} \) of the nearest circuit breaker Q1 is found with the help of the equations (4) and (5), choosing the higher calculated value.

\[
(4) \quad t_{ARQ1}^{off} = t_{rea} + t_{res},
\]

where \( t_{rea} = 0.2 \div 0.3 \) s is the standby time for reactivation of the circuit breaker again; \( t_{res} = 0.3 \div 0.5 \) s - is the reserve time, taking into account the changeability of \( t_{rea} \) [6];

\[
(5) \quad t_{ARQ1}^{off} = t_d + t_{res},
\]

where \( t_d = 0.1 \div 0.3 \) s is the deionization time; \( t_{res} = 0.3 \div 0.5 \) s - the reserve time, taking into account the scatterings of \( t_d \).

- In case of unsuccessful AR, all reclosers near the AR point switch off at the same time (in this case R1 and R2). The time for their switching off - \( t_{ARP1}^{off} \) and \( t_{ARP2}^{off} \) - is coordinated by the time for reclosing off \( t_{ARQ1}^{off} \) for the AR of switch Q1, setting a delay of \( \Delta t_{P1} \). The generalized record for the switching off times of n number of reclosers in the algorithm is the following:

\[
(6) \quad t_{ARP1}^{off} = t_{ARP2}^{off} = \ldots = t_{ARPn}^{off} = t_{ARQ1}^{off} + \Delta t_{P1}.
\]

- The activation time for the AAR breaker is

\[
(7) \quad t_{AR}^{on} = t_{ARP}^{off} + \Delta t_{ABP}.
\]

- The recloser with the highest number (Rn) from branch 1 is switched on with time

\[
(8) \quad t_{Pn}^{on} = t_{AR}^{on} + \Delta t_{Pn}.
\]

- The reclosers with decreasing numbers are switched on sequentially with the following times:

\[
(9) \quad t_{Pn}^{on} = t_{ABP}^{on} + \Delta t_{Pn}; \quad t_{Pn-1}^{on} = t_{Pn}^{on} + \Delta t_{Pn-1}; \ldots
\]

\[
= t_{P2}^{on} + \Delta t_{P2}; \quad t_{P1}^{on} = t_{P2}^{on} + \Delta t_{P1}.
\]

- By analogy, the setting parameters for branch 2 in Fig. 8 are selected, considering the short circuit in the area between the breaker Q2 and the recloser, nearest to it.

With the input data for the number of reclosers n in the considered branch and the times \( t_{rea}, t_{res}, t_d, \) by means of the developed software, the setting parameters of the RP in case of a short circuit in
branch 1 are determined. The switch-off times $t_{off}^{ARP_1}, t_{off}^{ARP_2}, \ldots, t_{off}^{ARP_n}$ of the reclosers $R_1, R_2, \ldots, R_n$, respectively, in the first branch of the network, are determined, as well as the switch-on times, $t_{on}^{P_1}, t_{on}^{P_2}, \ldots, t_{on}^{P_n}$ of the reclosers $R_1, R_2, \ldots, R_n$.

To calculate the time settings for the opposite branch, the data for the breaker $Q_2$ are set and the calculations performed analoguously, observing the switching sequence.

The developed algorithm for determining the settings of the response times for activation and switching off the AAR and the reclosers is applicable for unilaterally and bilaterally supplied branches of the distribution electrical networks.

9. Conclusions

- An algorithm for coordination of the response times of the devices for automatic sectioning of branches with two-sided power supply with connected DES has been developed.
- It is recommended that an adaptive reconnection circuit with high-speed reclosers, installed near generators, test the mode parameters before reconnection and block it if a permanent short circuit is detected.
- The correct determination of the settings for the AAR and the reclosers in branches with bilateral power supply allows to increase the efficiency of operation of the DRP in electrical networks with DES.

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