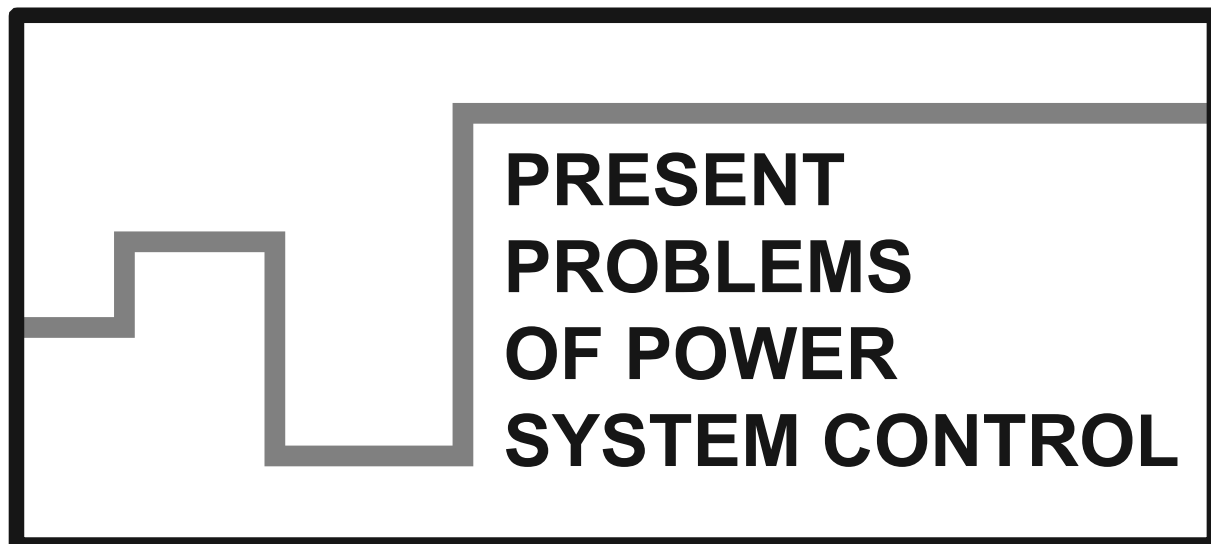


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*vacuum circuit breaker, double-break vacuum interrupters  
SF6 circuit breaker, capacitor banks, transient recovery voltage,  
dielectric strength, breaking capacity*

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## **TRANSITIONAL PROCESSES AT CAPACITIVE CURRENTS SWITCHING-OFF BY SINGLE AND DOUBLE-BREAK INTERRUPTERS OF VACUUM CIRCUIT BREAKERS**

Vacuum circuit breaker technology based on double-break vacuum interrupters has become the most requirements of high voltage circuit breakers that not environmentally harmful. The vacuum interrupter has an excellent ability to deal with the steep rising part of the transient recovery voltage, which makes it faster in the current interruption process. This paper presents results of computer simulations conditioned by capacitive currents switching-offs by using single and double interrupters of vacuum circuit breakers. These results demonstrate that use of double-break circuit breakers leads to notable decreasing of switching overvoltages and allows in the same time to meet the dielectric requirements for high voltage vacuum circuit breakers.

### 1. INTRODUCTION

According to the dielectric strength, SF6 has better behavior than vacuum. That is why SF6 has generalized as insulating and as arc quenching medium. Under normal conditions, SF6 is an inert, nonflammable, non-corrosive, odorless and non-toxic gas. However, at temperatures over 1000 °C, SF6 decomposes to gases including S<sub>2</sub>F<sub>10</sub> which is highly toxic. Fortunately, the decomposition products recombine abruptly after arc extinction (when the temperature goes down) [1]. SF6 has been labeled as one of the major global warming gases, since the 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change [2]. Hence,

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there is an urgent need to study new generation of high voltage circuit breakers that not environmentally harmful.

Note in this view that working-up of the new generation of high-voltage circuit breakers with carbon and nitrogen dioxides as an arc quenching media begun in the end of the last century had given the negative results [3]. It means that vacuum and SF6 circuit breakers are staying the preferable ones.

As it is known in vacuum circuit breakers (VCBs) the quenching media is a vacuum, so there is no risk for the environment. Another advantage of VCBs is the higher dielectric strength restoration after current zero in comparison with other types of circuit breakers. The problem of using VCB in high voltage applications is related to the high voltage capability of a single gap between electrodes. The breakdown characteristics have very high dependence of electrode area, and the dielectric strength with the contact gap. On this way, in vacuum breakdown, the breakdown voltage is proportional to the square root of the gap length. Thus, a longer gap is necessary for the vacuum interruption. But this technology makes the circuit breaker bigger and leads to the problem of arc control. It appears a high arc voltage noise, which indicates that the vacuum arc is unstable in a long gap [1, 2].

The study of circuit breakers based on the vacuum interrupters in series began in the 1960s. During the past period the patent applications were made by several manufacturers in the USA and Japan but none was applied in the industry because of technical conditions. With the development of large-capacity vacuum circuit breakers, a new round of research is proceeding in the 21st century [2, 4, 5].

So the main purpose of this research is to focus on VCBs only. In this research all capacitor banks switching-off processes were performed by using single and double interrupters of VCBs. A simulation results were performed by using PSCAD /EMTDC program. The transitional recovery voltages are compared in deferent interruption conditions in this research.

## 2. THEORETICAL BASES OF THE CASE UNDER STUDY

The connection scheme and equivalent electrical network for the case under study (capacitor banks of rated voltage 110 kV switching-offs) are shown in fig. 1. The figure shows the connections of single and double interrupters of the circuit breaker.

The numerical values of the connection scheme parameters for single phase representation used for computer simulation are shown in table 1. Note that, the capacitance value of capacitor bank shown in case of 37 MVA<sub>r</sub> rated jet power.

While carrying out the present research we had applied a mathematical model described in [6, 7]. The known phenomenon of current chopping was modeled in accordance with [6, 8]. Electrical strength and breakdown voltage of vacuum circuit breakers had been given in the numerical models in accordance with [6, 9].

Table 1. Connection scheme parameters for single phase representation

$R_S$ [ $\Omega$ ]	$L_S$ [mH]	$G_L$ [s]	$C_L$ [ $\mu$ F]	$G_C$ [s]	$C_C$ [ $\mu$ F]
0.2	23	$10^{-3}$	1.5	$10^{-7}$	10

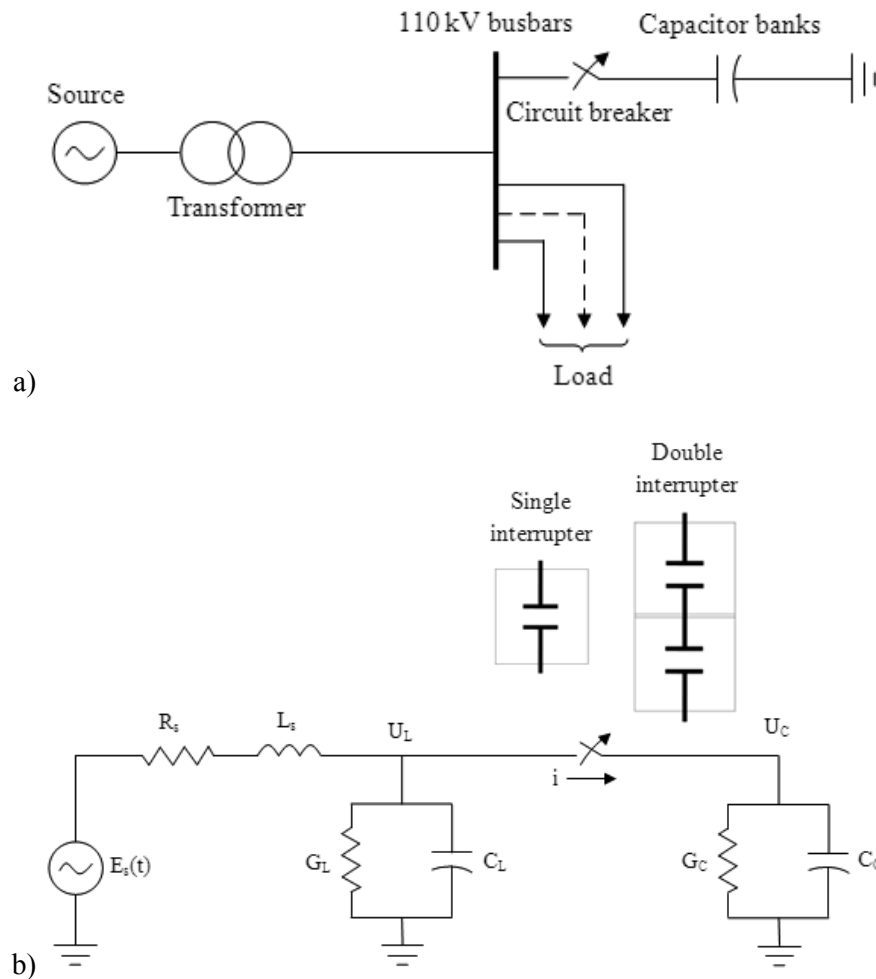


Fig. 1. The scheme and the network under consideration:  
 a) connection scheme; b) simulated network (index s concerns to the source parameters,  
 l – to the load parameters, c – to the capacitor banks parameters)

### 3. CIRCUIT BREAKER DIELECTRIC STRENGTH

It is known that when the interrupter contacts of circuit breaker starts to separate from each other the breakdown voltage of the gap starts to increase. After the arc has been extinguished, the race between transient recovery voltage (TRV) and dielectric withstand of the interrupter begins. When the TRV exceeds the dielectric withstand of the interrupter a breakdown occurs and creates a conducting path between the two contacts. Then the TRV jumps back to zero and does not start to rise again before the

arc is extinguished. Therefore the dielectric withstand of the circuit breaker is a significant parameter for the switching analysis.

For VCBs the most of authors use linear restoration law [10, 11]. But this law is not quite suitable to the physical nature (decreasing of strength at increasing of inter-contact distances) of vacuum inter-contact gaps [12, 13]. Therefore for modeling the dielectric properties of the inter-contact spaces we used the logarithmic law of dielectric strength restoration in VCBs presented in [14]. This law takes into account both inertia of contact and inconstancy of strength of vacuum gaps. The logarithmic restoration law for dielectric strength is given by the following empirical formula:

$$V_{str}(t) = 191.43 \log \left\{ 1 + 5.75 x_m \left\{ 1 - \cos \left[ \frac{\pi(t - t_{off})}{T_{full}} \right] \right\} \right\} \quad (1)$$

where:  $V_{str}(t)$  is the acceptable law of circuit breaker's dielectric strength restoration;  $X_m$  is the maximum distance between contacts;  $t$  is the time;  $t_{off}$  is the initial instant of contact separation;  $T_{full}$  is the full switch-off time of vacuum inter-contact gap [5].

#### 4. RESULTS OBTAINED AND DISCUSSION

The aims of these simulations divided into two directions. At first, comparing the results obtained from capacitor banks switching-off by using single and double interrupters of VCBs. In this case the contacts of the two vacuum interrupters are simultaneously separated. At second, it's important to find the interaction relationship between the two vacuum interrupters during the current interruption process and to obtain the best strategy to open contacts. In this direction, the VCB model is obtained by connecting the model of double-break interrupters in series. The voltage distribution between the two vacuum interrupters is simulated under deferent contact parting sequences. Each vacuum interrupter model is represented by the respective contact resistance before contact separation and by the respective dielectric strength restoration after contact separation. We can adjust the initial moment of the dielectric strength model by changing the separation time of the two contacts.

The results of capacitor banks switching-off with rated jet powers of 37-112 MVA are presented below. The transitional currents and recovery voltages in cases of single and double interrupters of VCB are shown in tables 2, 3, respectively.

As shown the overvoltages values for both cases (single and double interrupters) do not exceed the rated amplitude's triple value which is maximum allowable for

the 110 kV insulation level (tables 2, 3). Comparing the results shown we can state that using of double interrupters of VCB causes less magnitude of overvoltage, inter-contact recovery voltage, and overcurrent. The reductions are equal to 27%, 65%, and 23% for capacitor bank voltage, interrupter voltage, and interrupter current respectively. It means that, double interrupters of VCB have more efficient breaking capability during current interruption process. At the same time the recovery voltage divided symmetrically across the double interrupters. It means that, the recovery voltage is not great influencing the voltage divisors (capacitive and resistive ones) that connected between poles of circuit-breakers.

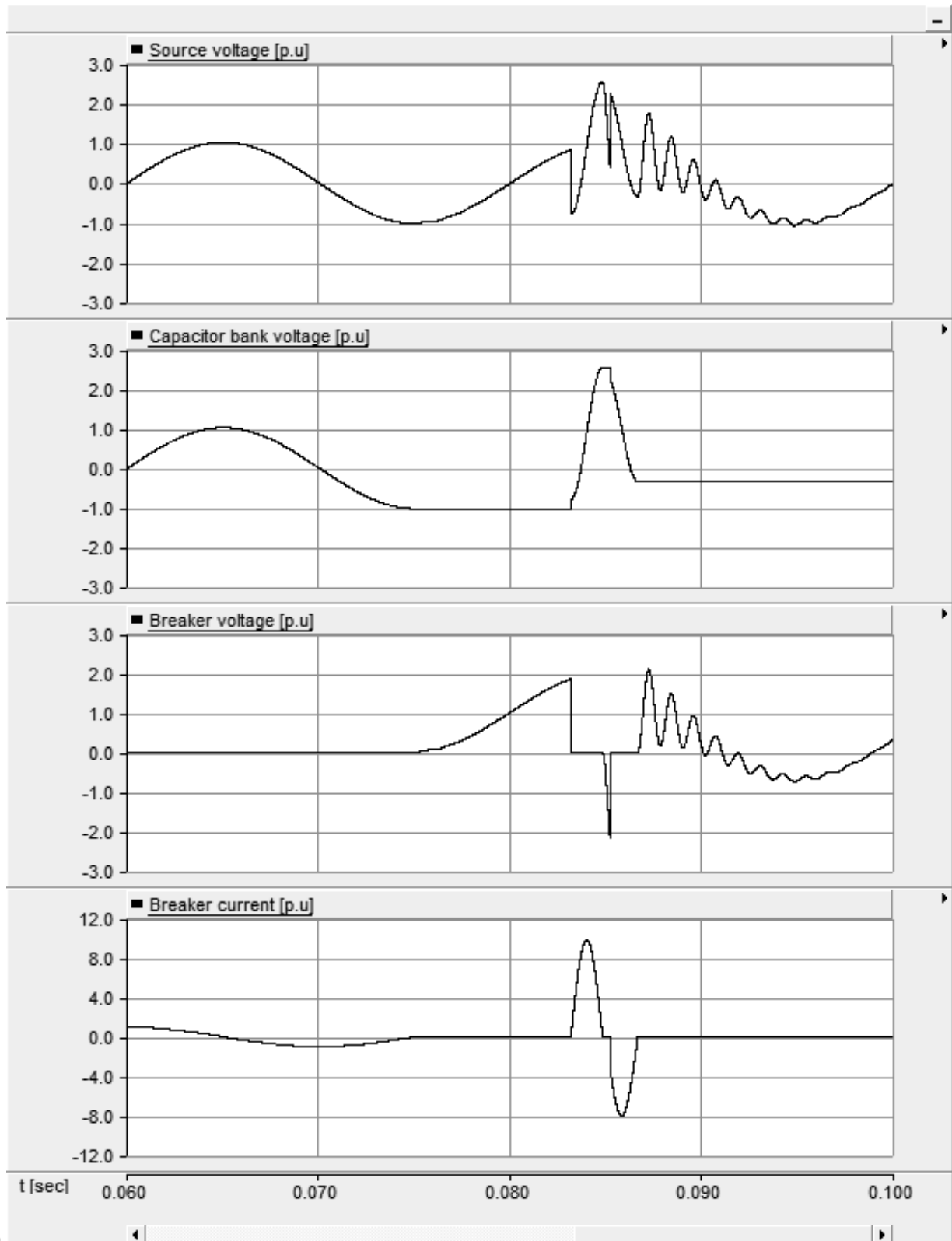
Table 2. Overcurrents and overvoltages in case of single interrupter VCB for range of jet powers

Capacitor bank [MVar]	Capacitor bank voltage [p.u.]	Breaker voltage [p.u.]	Breaker current [p.u.]
37	2.54	2.16	9.84
56	2.68	2.39	8.68
75	2.75	2.56	7.80
112	2.84	2.69	6.81

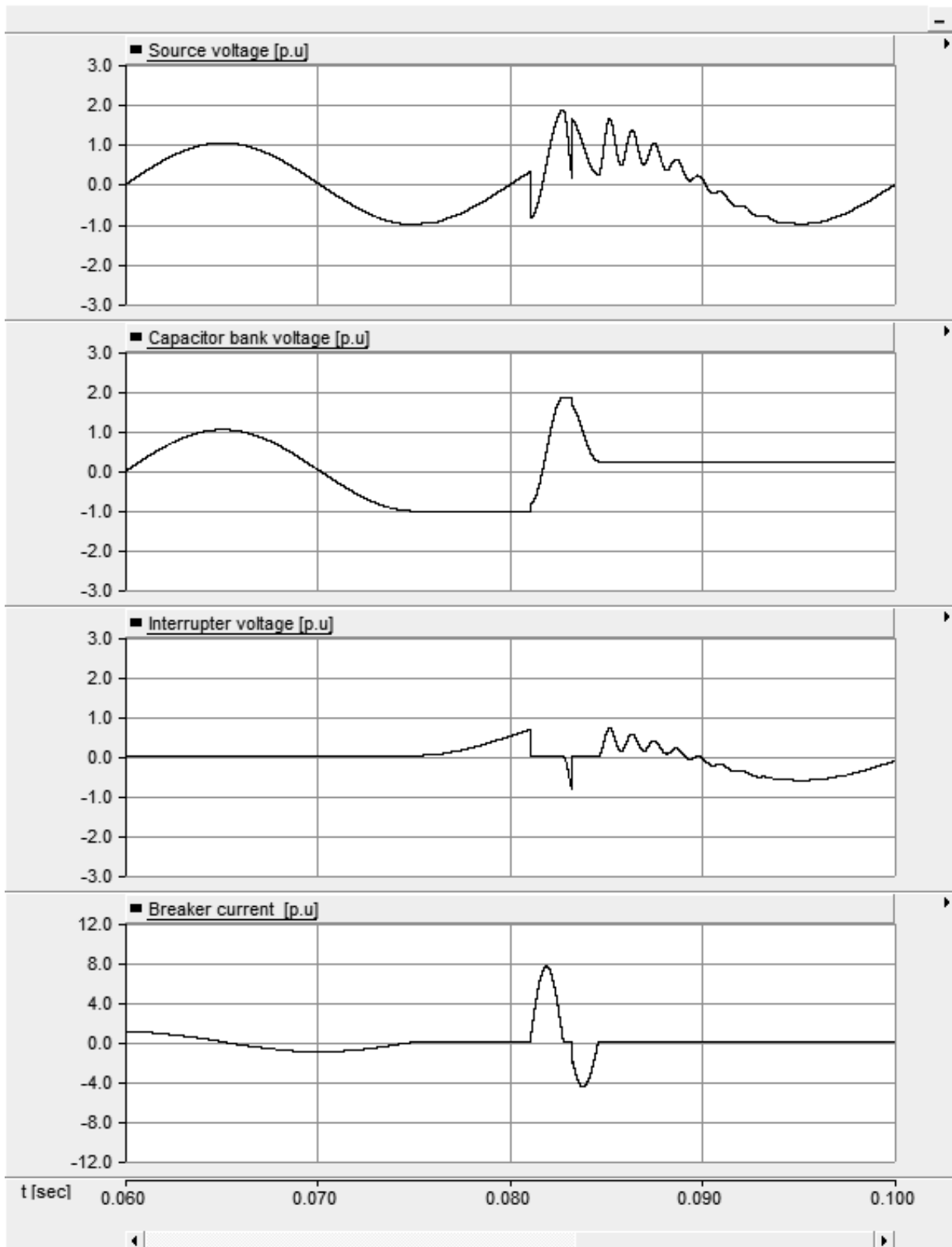
Table 3. Overcurrents and overvoltages values in case of double interrupters VCB for range of jet powers

Capacitor bank [MVar]	Capacitor bank voltage [p.u.]	Interrupter voltage [p.u.]	Breaker current [p.u.]
37	1.85	0.85	7.63
56	2.02	0.88	6.83
75	2.14	0.91	6.19
112	2.34	0.96	5.39

Some calculated transitional voltages and currents taken place at capacitor banks switching-off with jet powers of 37 and 112 MVar are presented in figures 2, 3, respectively. Note that, the recovery voltage shown in figure 3 for each interrupter in case of double interrupters. As shown in figure 2, for the case of 37 MVar capacitor banks switching-off, we had only two repeated re-ignitions for both cases (single and double interrupters). But from figure 3, for the case of 112 MVar capacitor banks switching-off, we had three repeated re-ignitions in case of single interrupter and two repeated re-ignitions in case of double interrupters. It means that, using of double interrupters of VCB may also reduce the probability of repeated re-ignitions.

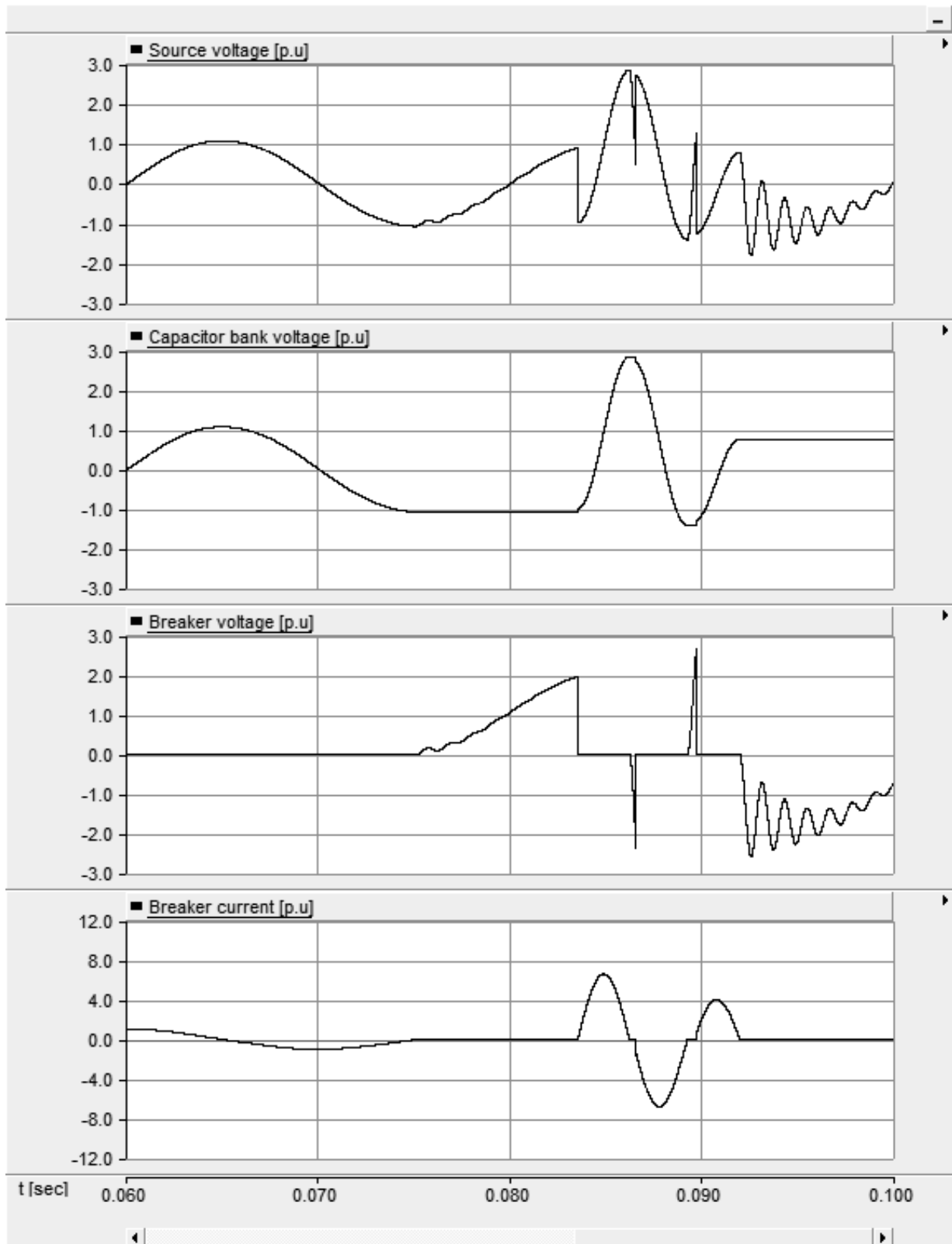






b)

Fig. 2. Transitional voltages and currents conditioned by 37 MVar capacitor banks switching-off of VCB: (a) single interrupter; (b) double interrupters



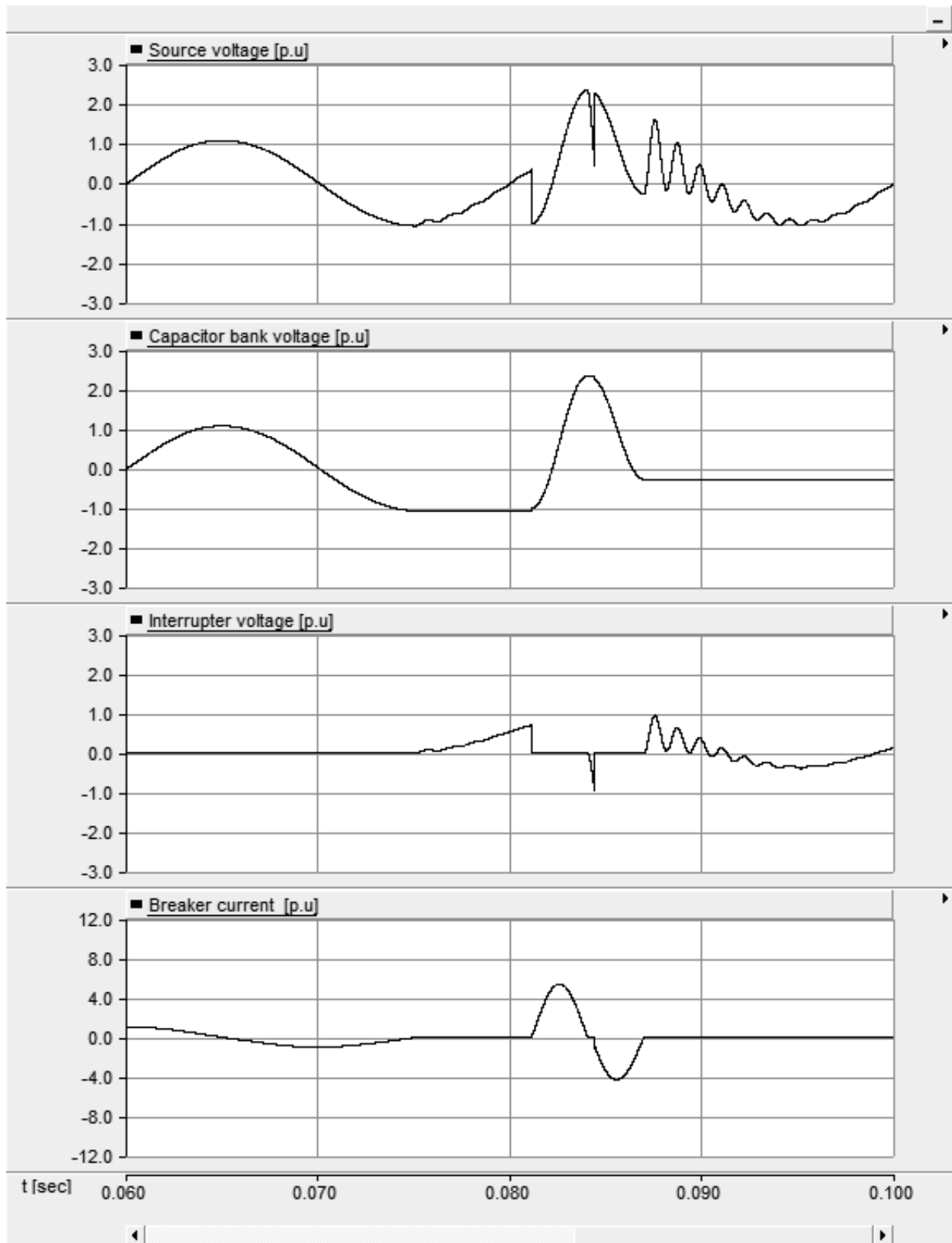


Fig. 3. Transitional voltages and currents conditioned by 112 MVar capacitor banks switching-off of VCB: (a) single interrupter; (b) double interrupters

For the second aim of this research we had found that, if one of the two interrupters switched-off after/before the other interrupter, during this time interval the interrupter which switched-off at first will be withstand the TVR alone. So it's important to mention that, when the contacts of the two vacuum interrupters are not simultaneously separated, the performance is not significantly differing from the case of single interrupter switching-off.

## 5. CONCLUSION

Use of vacuum circuit-breakers with series interrupters leads to a notable decreasing of overvoltages at switching-off high-voltage capacitor banks. This has taken place because that rate of rise the dielectric withstand of the series interrupters is faster than the same rate of a single interrupter of the equivalent spacing. In other words use of more than one break let to prevent notable decreasing of dielectric strength at contacts separation as it occurs for single-break circuit-breakers. The results indicate that, with the development of large-capacity vacuum technology, it is possible to meet the dielectric requirements of VCBs to use it with applications more than 110 kV.

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