



PS2 – Poster-08



The Distance Principle Implementation in Microprocessor Out-of-Step Protection

Vladimir E. GLAZIRIN¹, Gleb V. GLAZIRIN², Oleg V. TANFILIEV²
Power System Automation Institute¹, Novosibirsk State Technical University²
Russia
tanfiliev@ngs.ru

KEYWORDS

Emergency control, out-of-step conditions, out-of-step protection system.

1 INTRODUCTION

The most serious consequences for consumers are associated with out-of-step conditions caused by synchronous operation failures in the power system. The Out-of-Step Protection System (OSPS) is used for the elimination of such dangerous conditions.

The distance principle using the information obtained at the installation site is one of the most common principles of the OSPS. Main disadvantages of the devices based on this principle and assembled of analogue relays (electromechanical and microelectronic relays) are widely known. These disadvantages are caused by not the distance principle, but its technical implementation. Modern microprocessor technologies and advanced techniques of information processing provide different ways for performance improvement and out-of-step detection reliability, operation during power swings and short circuits, and implementation of new complex algorithms for efficient out-of-step detection under both symmetrical and asymmetrical conditions.

The aim of this work is to develop principles and algorithms of the OSPS which provide reliable out-of-step detection, operation during power swings and short circuits, and correct operation under asymmetrical conditions.

2 OSPS PRINCIPLES OF OPERATION

For out-of-step detection, the OSPS uses a well-known principle [1] based on impedance vector monitoring. Out-of-step detection is realized by the out-of-step detection module (OSDM) which analyzes impedance locus behaviour. In fact, the OSDM is a software module (see Figure 1).

The OSDM algorithm realizes functions of the stepwise cyclic OSPS with a control of the center-of-swings position: it starts on the impedance and monitors the power reversal (*power reverses its sign and direction when the impedance vector passes between two planes*). The unit which controls the power flow direction is the Directional Power Relay Unit (DPRU).

For starting on the impedance, the OSDM has two operating areas in the complex plane Z for two units where the first area (the "Rough" Distance Relay Unit, RDRU) is placed into another (the "Sensitive" Distance Relay Unit, SDRU). These three units (i.e. the directional power relay unit, the rough distance relay unit and the sensitive distance relay unit) represent the OSDM.

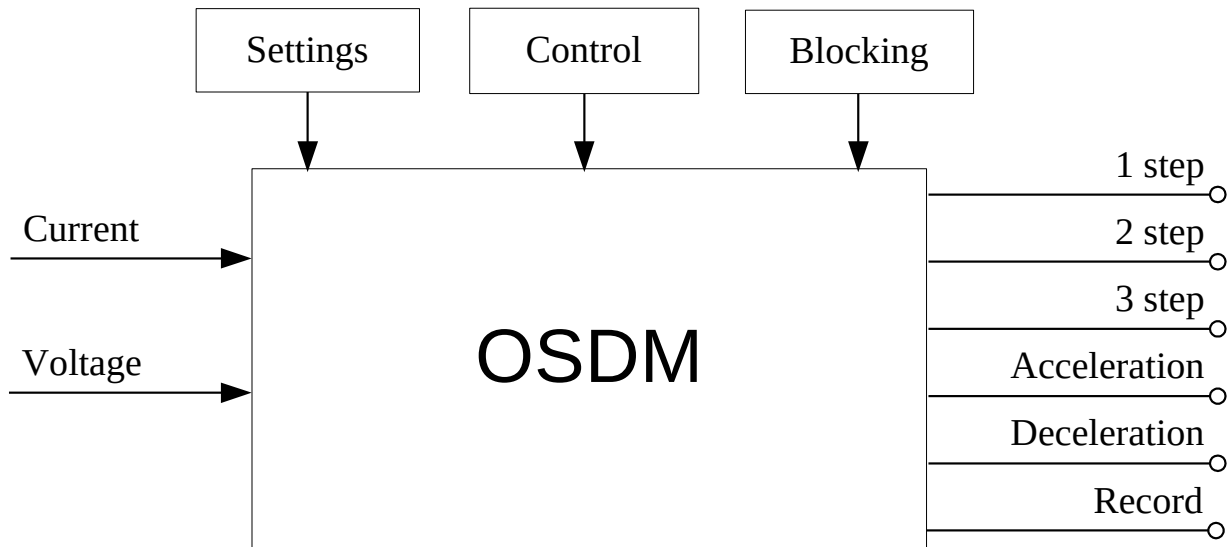


Fig. 1: The Out-of-Step Detection Module block diagram

3 OSDM TRIPPING CHARACTERISTIC

Field experience of emergency control automatics shows that conventional devices do not comply with specified requirements. The reasons are the following.

The form of tripping characteristics of measuring units used in typical boards and some modern microprocessor devices is convenient for the development of distance protection that complicates the choice of settings and the coordination of the rough distance relay, the sensitive distance relay and the directional power relay units.

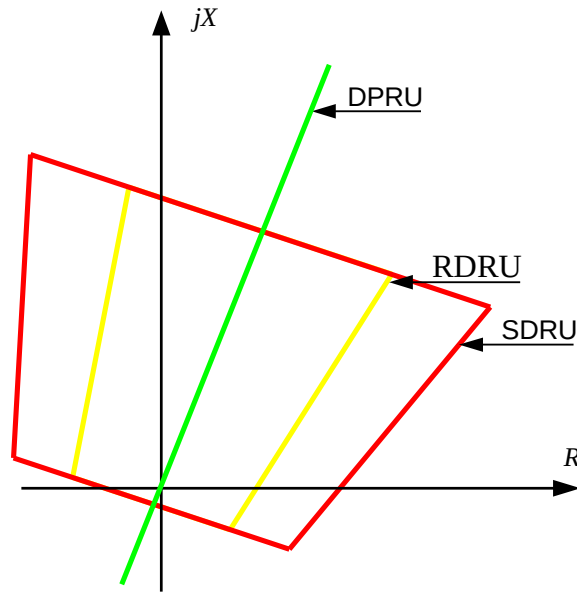
Implementation of logic algorithms for simultaneous operation of three measuring units taking into account time functions is very complicated, and it requires large hardware costs that significantly reduce reliability of the device. To eliminate these disadvantages, the tripping characteristic conforming to the following requirements is suggested to be used:

- Under out-of-step conditions, the impedance vector is desirable to be in and out the operating area for about the same time, that allows achieving the maximum possible "failure-to-trip" slip (*this is the value of slip at which the relay protection is failure to operate*);
- Since loci forms of internal out-of-steps are circles whose centres are located in one side with the electrical center of swings, it is necessary to choose equal trapezoid base lengths, taking into account that smaller bases should be located close to centres of circles (these circles are out-of-step loci).

The equilateral trapezium tripping characteristic randomly shifted relative to the origin of coordinates conforms to these requirements. For the rough distance relay and the sensitive distance relay units, the tripping characteristic has the same height but different base lengths. Generally, bases should have the same direction as the locus. The tripping characteristic is shown in Figure 2.

Proposed technical solutions for tripping characteristics allow achieving the maximum possible "failure-to-trip" slip and detecting out-of-steps having small periods. It should be noted that the random shift of the tripping characteristic relative to the origin of coordinates gives more possibilities for offsetting from external out-of-steps.

The main difficulty of choosing settings for typical boards is to coordinate tripping characteristics of power and impedance measuring units. To overcome these difficulties, the tripping characteristic of the measuring unit is suggested to be realized as the straight line in the impedance complex plane which passes through the base midpoints of trapezium tripping characteristics for distance units. This approach provides the coordination of tripping characteristics of the out-of-step detection modules.



DPRU – Directional Power Relay Unit
RDRU – Rough Distance Relay Unit
SDRU – Sensitive Distance Relay Unit

Fig. 2: The Out-of-Step Detection Module tripping characteristic

4 METHODS OF OFFSETTING FROM EXTERNAL OUT-OF-STEPS

When choosing settings for the OSPS, one of the defining conditions is offsetting from external out-of-steps. It is rather difficult to provide selectivity for typical OSPSs. To increase the efficiency of offsetting from external out-of-steps, the following technical solutions were proposed:

- Limitations of tripping characteristic position in the complex impedance plane were eliminated. Characteristics can be located randomly in the complex plane with the random shift and random angle relative to the origin of coordinates. This gives more possibilities for detecting internal out-of-steps and offsetting from external out-of-steps (Figure 3);

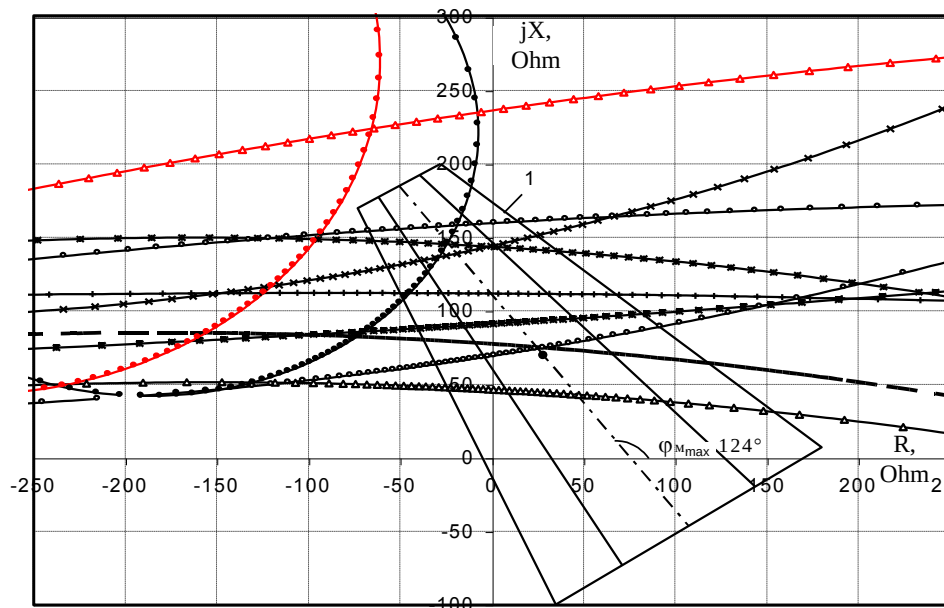


Fig. 3: The tripping characteristic of the OSDM shifted relative to the origin of coordinates. Loci of impedances at external out-of-steps are marked with red colour, whereas loci at internal out-of-steps are in black

- It is possible to realize more than one OSDM within the OSPS that improves the functionality of the device (Figure 4). This approach is particularly important in complex electric power systems consisting of several power transmission lines (these power lines have different points of connection to the system) under out-of-step conditions.
- Blocking OSDMs for offsetting from external out-of-steps can also be realized. This is very important when external and internal out-of-step loci are close enough in the range of $\delta \approx 180^\circ$ (it is the angle between EMFs of synchronically operated parts of the power system);

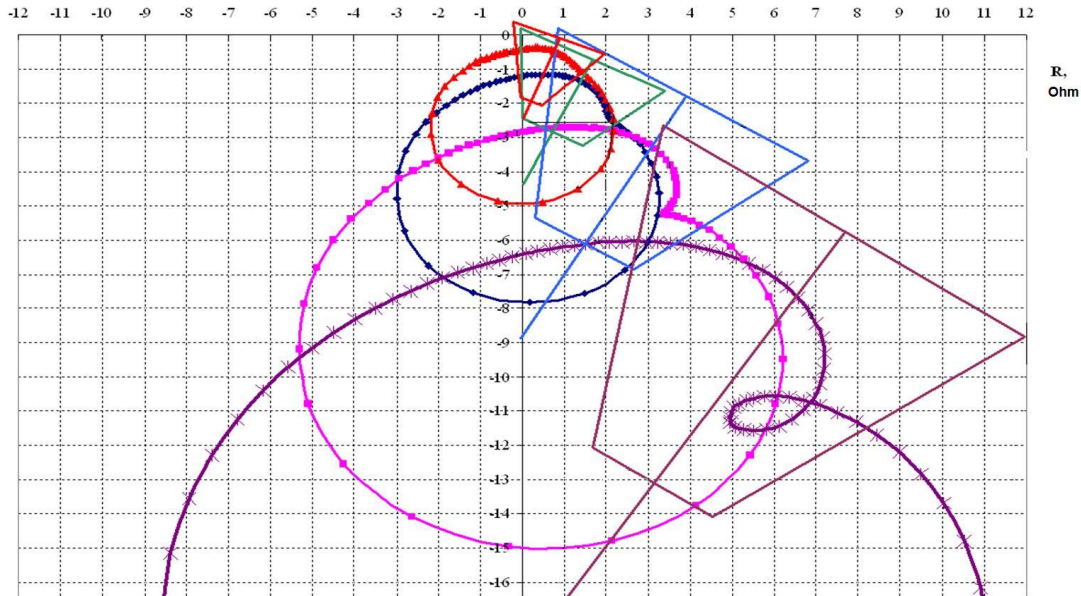


Fig. 4: Example of using several OSDMs for out-of-step detection

- Using of the digital description for the tripping characteristic of measuring units allows good possibilities for the adaption of the characteristic to the change of the power system state and the configuration of the controlled network. The change of settings can be quickly performed by a multiposition switch or automatically by the program.

Technical solutions described above give possibilities for the OSPS to offset from external out-of-steps and provide selectivity operation.

5 OUT-OF-STEP DETECTION ALGORITHMS AND OFFSETTING FROM POWER SWINGS AND SHORT CIRCUITS

To improve quality and productivity of OSPS operation, methods of out-of-step detection and offsetting from short circuits and power swings based on pattern recognition theory are proposed. Parallel data processing by methods of pattern recognition theory allows saving previous duty-identifying patterns in rather simple and visual form that greatly facilitates their detection and identifies new patterns. The probabilistic approach for abnormal generator duties proposed in [2] is rather complex for the implementation and requires a lot of computations. Thus, the structural approach [3] is suggested to be used for the development of the out-of-step detection system. Information about impedance vector position relative to the operating areas of OSPS measuring units is proposed to be used as input data (initial data, input information) for the detection system.

Out-of-step detection is realized by analysis of the order of vector passing through the areas in the complex plane (these areas are formed by overlapping of measuring unit operating areas). Numbers of areas presented in Figure 5 correspond to the codes which characterize the state of the appropriate OSDM. Normal operation of the power system is determined in the "0" and "4" areas of the vector position depending on the direction of active power transfer. When the vector is located in the "0" area and out-of-step occurs, this vector rotates along a trajectory: first, it comes to the "2" area (the sensitive distance relay unit SDRU is activated), then moves to the "3" area (the rough distance

relay unit RDRU is activated), next comes to the "7" area (the directional power relay unit DPRU is activated). This corresponds to the activation of the OSPS in the first step (Figure 6).

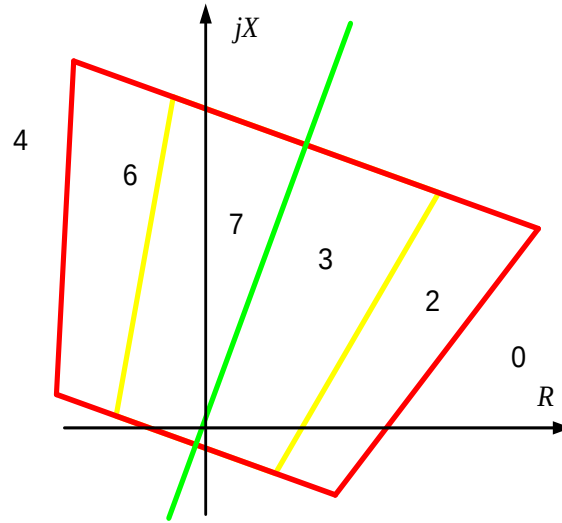


Fig. 5: The areas characterizing the OSDM state

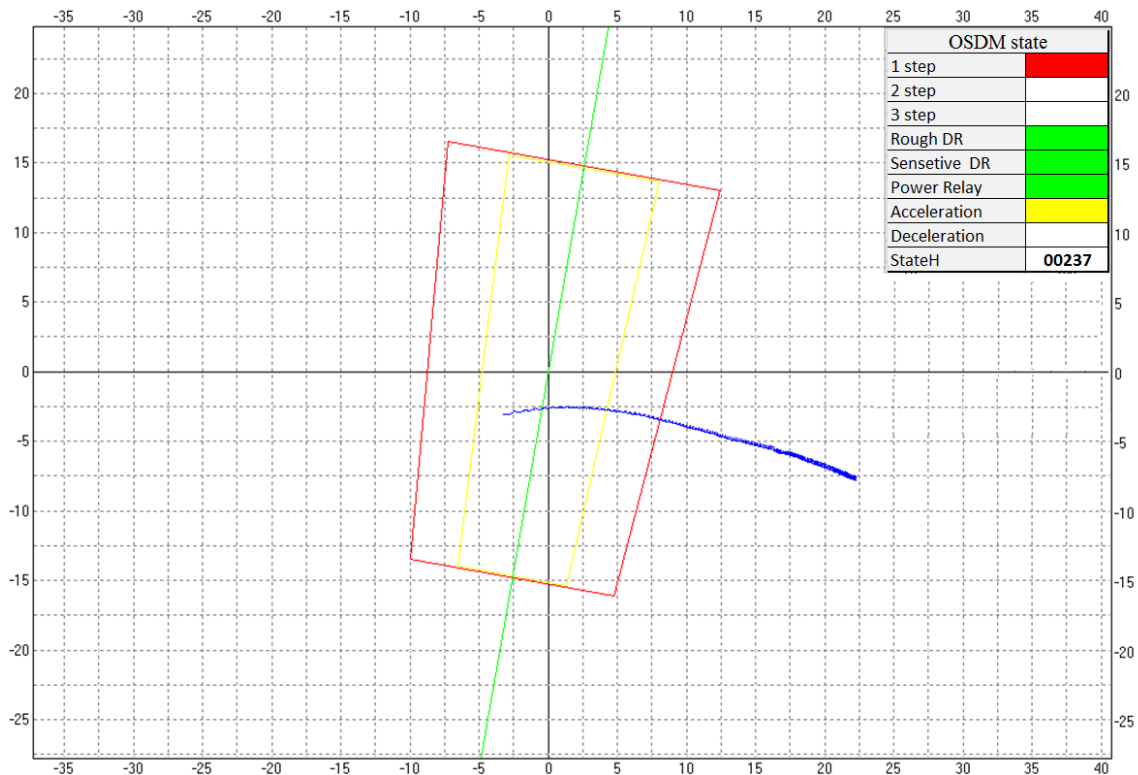


Fig. 6: Out-of-step detection

Power swing detection is performed when the impedance vector is located in one area for a long time or upon the order of its passing through different areas. If power swings are not so deep, the impedance vector either moves inside the "0" or "4" area or periodically passes between these areas outside the SDRU operating area. If power swings are deep, the vector can move from the "0" area to the "2" area, and then come back to the "0" area. In this case, the vector can also move to the "3" area, after that it returns to the "2" and further to the "0" areas. Vector $\dot{Z}_p$ is possible to come from the "4" area to the "6" area, and then come back to the "4" area. At deeper power swings, the vector can pass through the "7" area with further return to the "6" area, and then to the "4" area. When detecting

different patterns of power swings, the cycle counter is reset and the device does not operate (Figure 7).

Offsetting from short circuits is realized in the same way. At symmetrical short circuits, the impedance vector jumps to the operating area of the rough distance relay unit. Since the order of vector passing through the areas is not performed, the OSPS is not activated.

Parallel data processing allows realizing complex logic algorithms without additional hardware. Using of pattern recognition theory enables the development of efficient algorithms for out-of-step detection, as well as offsetting from short circuits (including the case when short circuit is located near the center of swings) and from power swings.

6 OSPS OPERATION UNDER ASYMMETRICAL CONDITIONS

Out-of-steps may occur in the power system under open-phase or deep symmetry conditions. Since open-phase out-of-step is not a rare event, and existing emergency control standards require out-of-step detection and elimination under these conditions, the special algorithm is realized in the OSPS for asymmetrical out-of-step detection. This algorithm is based on the control of the positive sequence impedance and its rate of change. The algorithm changing settings under asymmetrical conditions is proposed for the correct operation of the OSPS under these conditions. The algorithm is based on the detection of the moment when one conditions transit into another (from symmetrical to asymmetrical conditions). Negative and zero sequence parameters are the main features of asymmetrical conditions. The fault detector which is activated when current $\dot{I}_2$ or negative sequence voltage $\dot{U}_2$ occurs is realized. To avoid false operation, an additional blocking algorithm activated at open-circuit failures in voltage and current measuring circuits was employed.

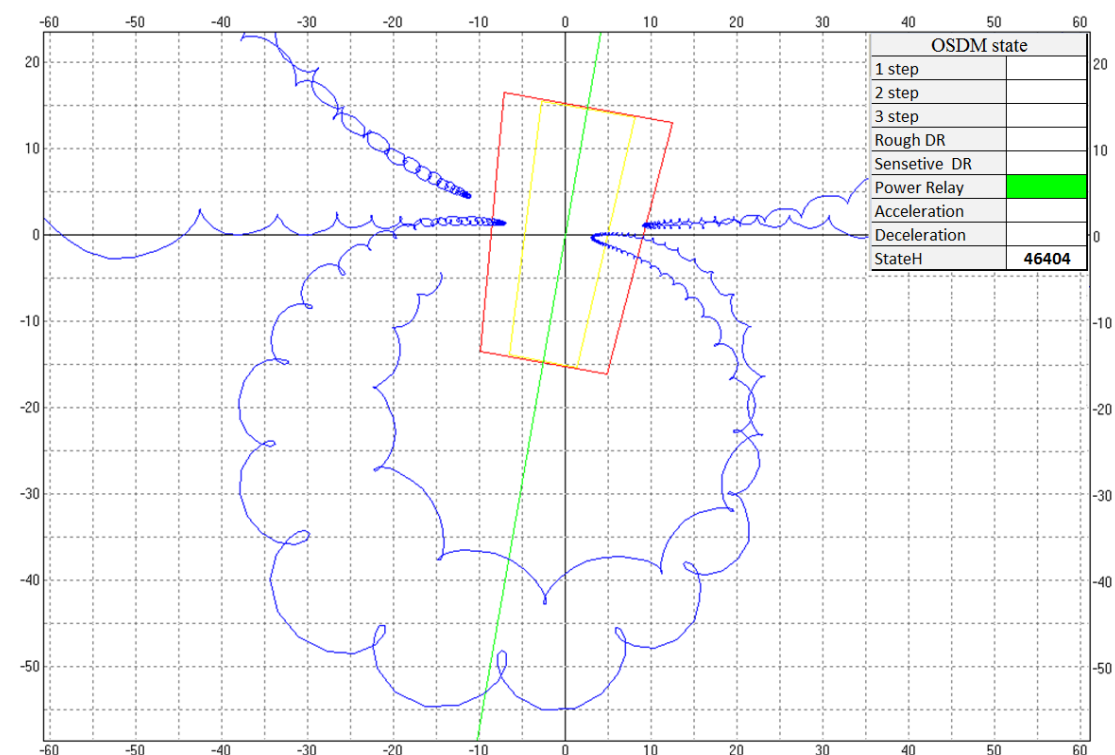


Fig. 7: Power swing detection

7 CONCLUSION

Proposed technical solutions significantly enhance functional capabilities of the OSPS:

- parallel data processing allows the development of efficient algorithms for out-of-step detection, and offsetting from short circuits and power swings;
- proposed tripping characteristic enables achieving the maximum possible "failure-to-trip" slip and detecting out-of-steps with a small period;

- the positive sequence impedance is used in the OSPS for the detection of out-of-steps under both symmetrical and asymmetrical conditions.

At the present time, 17 MP-ALARs (*the device MP-ALAR developed by CJSC*) have been installed and successfully put into experimental and industrial operation. By now, there have not been any false operations. For example, MP-ALAR installed in line 203 of the connection Ust-Khantayskaya HPP – Igarka Substation – Kureyskaya HPP was correctly operated under out-of-step conditions induced in the section between Ust-Khantayskaya HPP and Kureyskaya HPP.

REFERENCES

- [1] Gonik Ya.Ye., Iglitsky Ye.S. Out-of-step protection system. Moscow: Energoatomizdat, 1988. – 112 P. (in Russian).
- [2] Tadzhibaev A.I. Pattern recognition automated systems for electrical equipment. St. Petersburg: Energoatomizdat, St. Petersburg Branch, 2001. – 176 P. (in Russian).
- [3] Gorelik A.L., Skripkin V.A. Pattern recognition methods: Tutorial for institutes of higher education. – 3rd ed. Moscow: Vysshaya shkola, 1989. – 232 P. (in Russian).