

A New Intelligent Algorithm for Load Shedding Against Overload in Active Distribution Networks

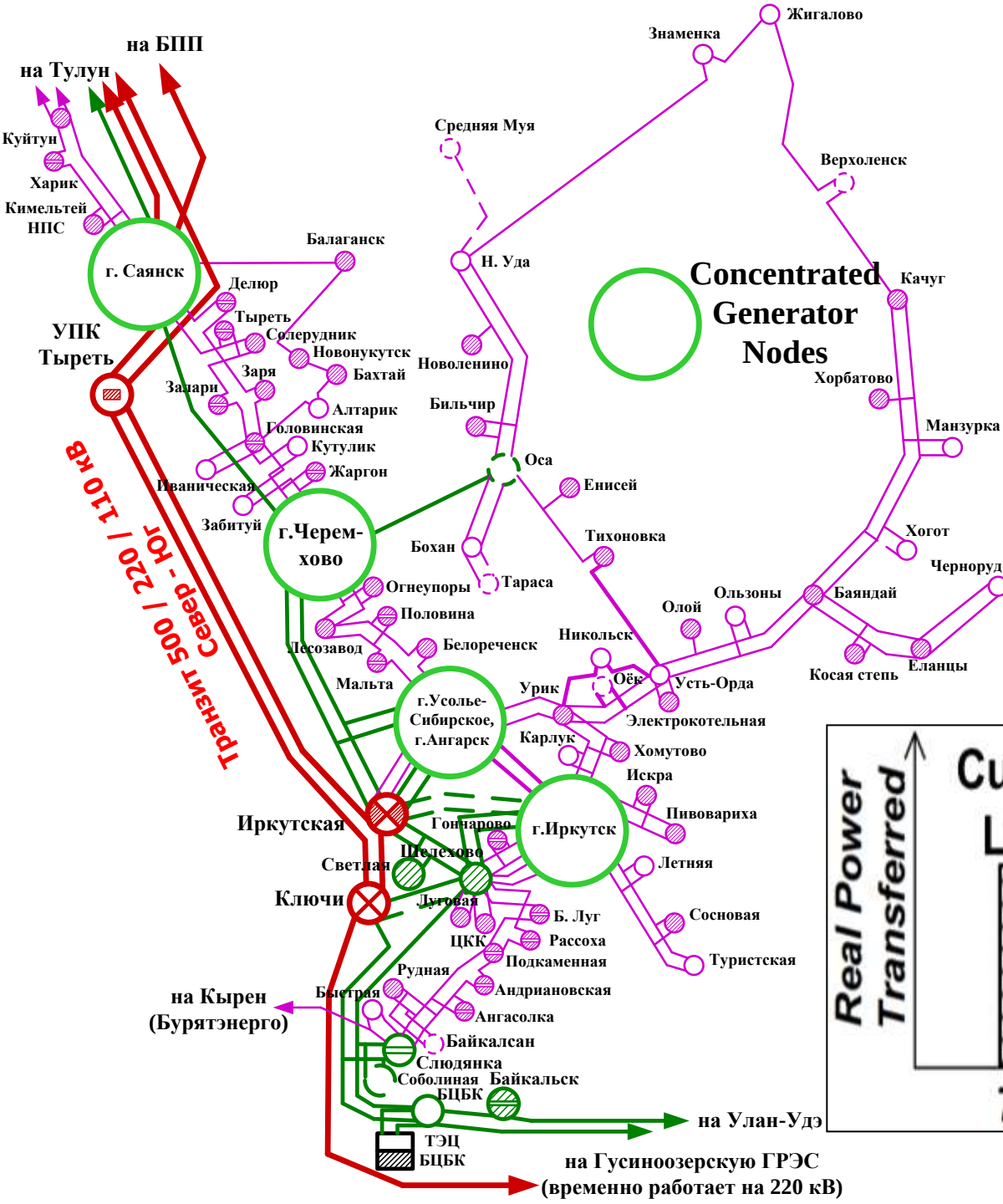
**Мультиагентный централизованный алгоритм
отключения нагрузки потребителей при
перегрузках в распределительных
электрических сетях**

Daniil Panasetsky

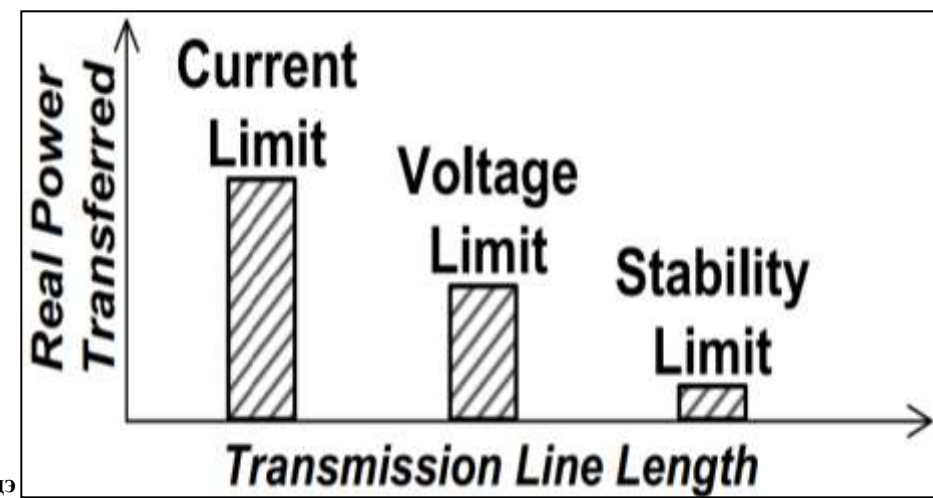
Victor Kurbatsky

Nikita Tomin

Melentiev Energy Systems Institute,
Russian Academy of Science



A kind of Smart Grid:
Intelligent Algorithm for Load Shedding
Against Overload in Distribution
Network



CURRENT SITUATION WITH LOAD SHEDDING

- Load shedding automation against overload conditions in the distribution networks is usually represented by **simple local devices that trip the local load** in case of overload of a controlled element (transformer, transmission line, etc.).
- Control actions of these local devices are **poorly coordinated or not coordinated at all, and volume of the control actions is excessive.**

NEW LOAD SHEDDING REQUIREMENTS

- **Minimizing the load shedding.** Existing algorithms usually implement redundant control actions to ensure the highest level of reliability and do not take into account the economic interests.
- **Raising the intellectual level of the algorithms.** Continuous development of the distribution network structure does not allow implementing the efficient control actions using only local principles.

THE NEW ALGORITHM REQUIREMENTS

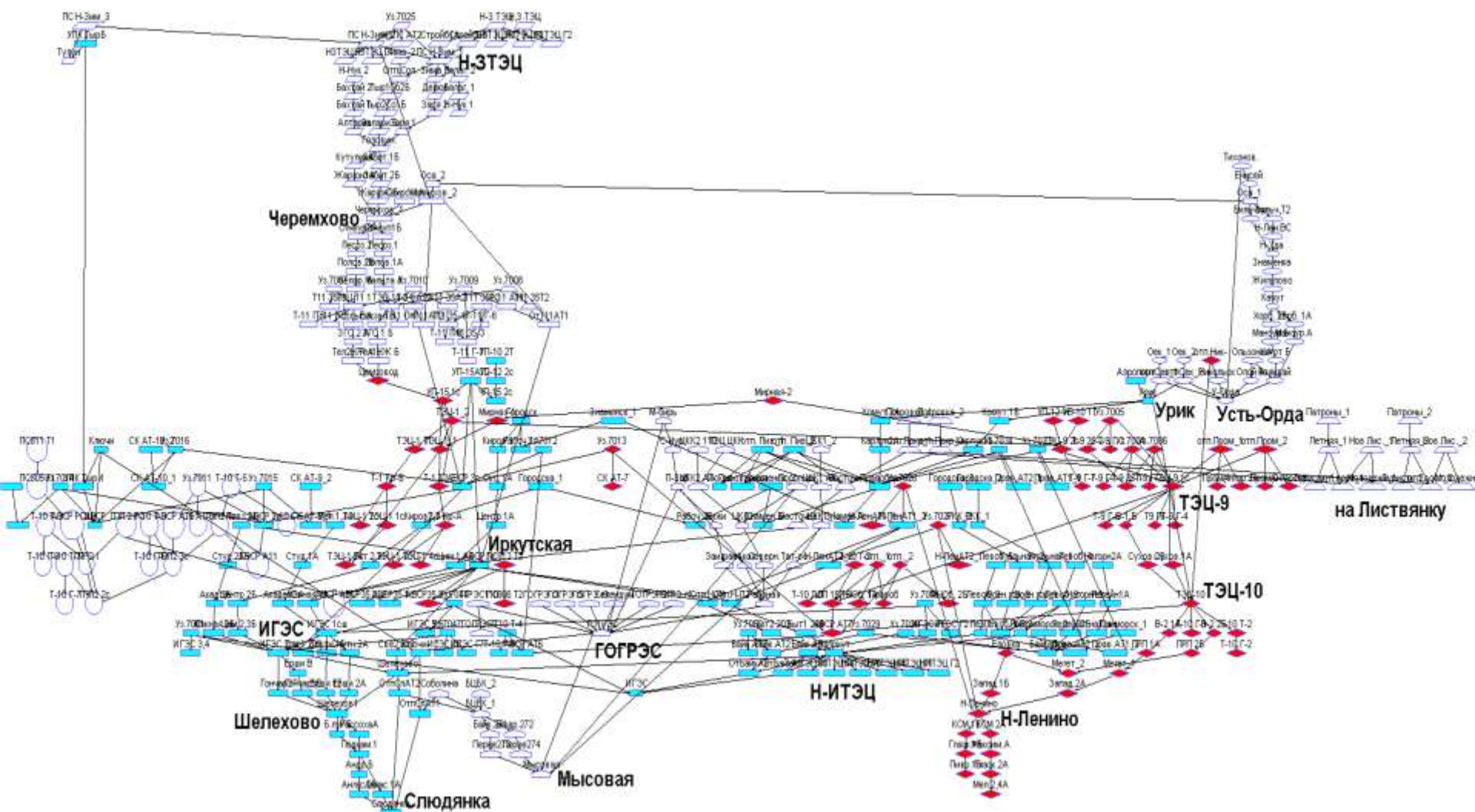
- **Partial decentralization.** Full centralization of a load shedding algorithm is not possible, because the number of controlled elements in distribution networks usually exceeds by far the number of controlled elements in the transmission networks.
- **The possibility of incorporating distributed generation.** The algorithm can take into account the presence of distributed generation sources in power systems and their properties.
- **Keep the balance between complexity and simplicity of implementation.** On the one hand, the algorithm is complex enough to provide an acceptable level of control action precision. On the other hand, it is simple enough to provide an acceptable speed of calculations.
- **Provides a high level of fault tolerance.** The algorithm does not fail in the case of uncritical loss of information. If the loss of information is critical, the algorithm either implements the excessive control actions, or delegate control to a power system operator with information about its failure.
- **High speed diagnostic self-testing** - the possibility of implementing an effective self-testing procedure is directly related to the requirement of maximum simplification of the algorithms.

- Decentralization problem is directly related to the decomposition task – splitting the system into subsystems for further formation of emergency control areas. Decomposition task can be reduced to a well-known problem of graph partitioning. We considered that absolute value of mutual conductance between network nodes can be used as an edge weight parameter.

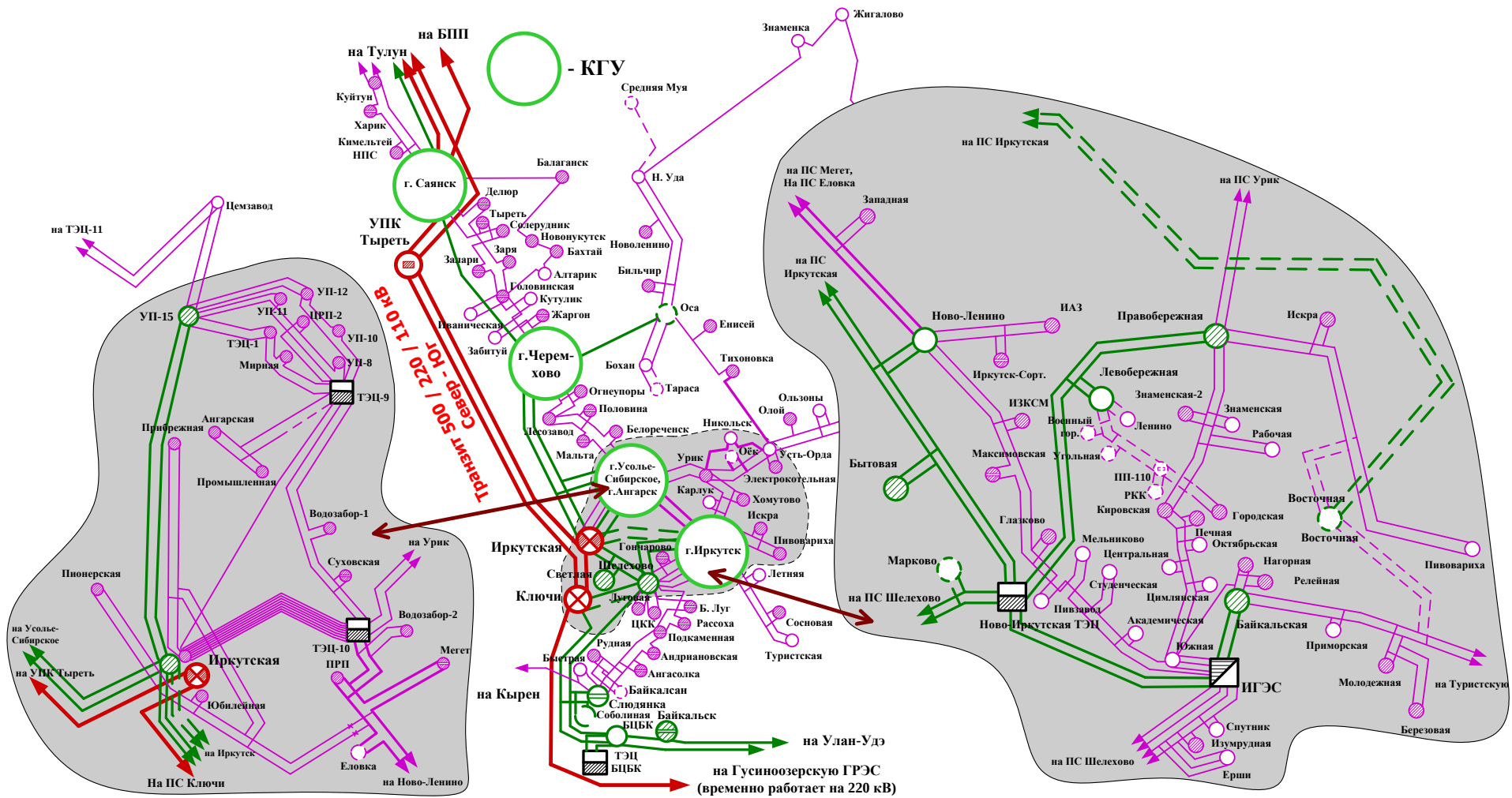
$$C(P)=\sum_{i\neq j}\sum_{v\in V_i,\bar{v}\in V_j}Y(v,\bar{v})$$



Emergency Control Area



Emergency Control Area



INCORPORATION OF DISTRIBUTED GENERATION

- It is necessary to take into account the redistribution of active power among generators after load shedding.
- This can be done accurately for example by using the dynamic model of the system, however, this approach is inadmissible in terms of time consumption.
- To take into account the dynamic properties of distributed generation it is proposed **to use a distributed slack bus model**, for which the active power balance can be written as follows:

$$\sum_{i=1}^{NG} (1 + K_G \sigma_i) P_{Gi} - \sum_{i=1}^{NL} P_{Li} - P_{LOSS} = 0$$

SENSITIVITY ANALYSIS. INFLUENCE COEFFICIENTS.

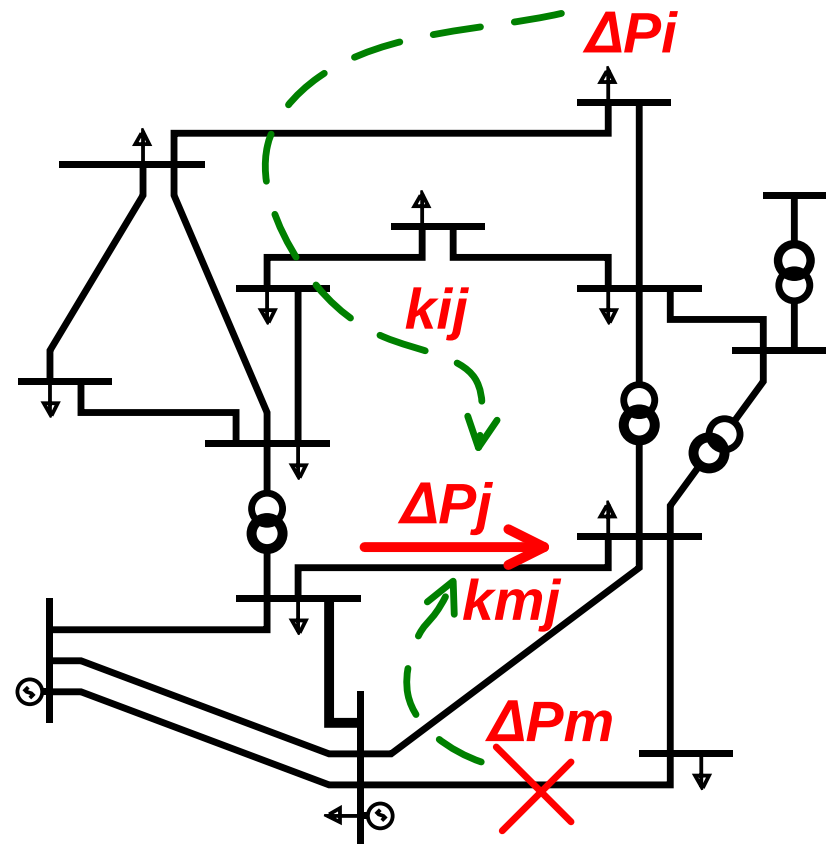
- The influence coefficient determining the influence of load shedding at node i on the change in the flow through link j :

$$k_{ij} = \frac{\Delta P_{line\ j}}{\Delta P_{load\ i}}$$

$k_{ij} > 0$
 $k_{ij} < 0$

- The influence coefficient determining the influence of disconnection of link m on a change in the power flow through link j

$$p_{mj} = \frac{\Delta P_{line\ j}}{\Delta P_{line\ m}}$$

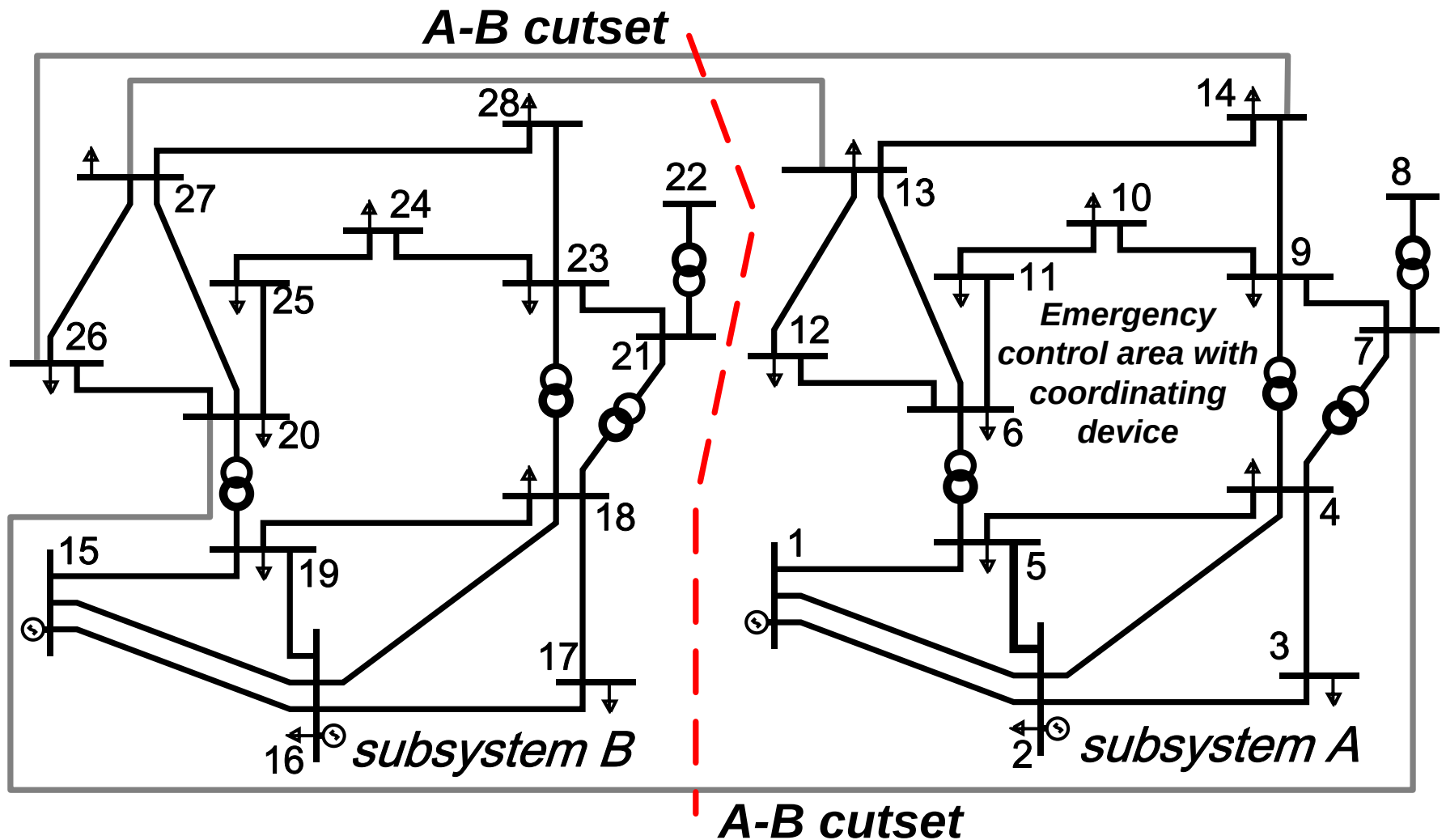


- The coefficients depend very little on the power system operating conditions and remain virtually unchanged for a given topology*

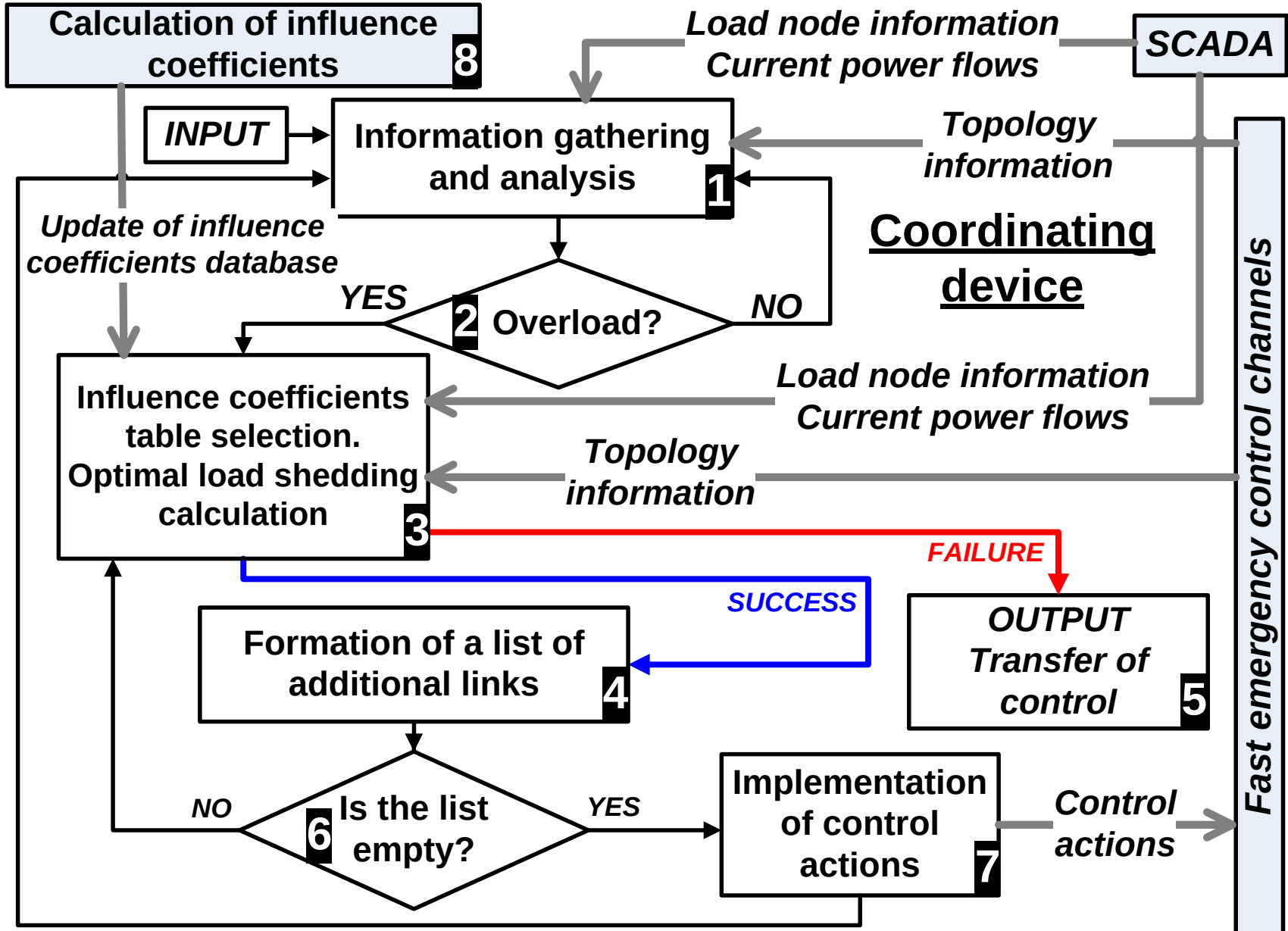
NECESSARY CONDITIONS FOR THE ALGORITHM IMPLEMENTATION

- Electric power system must first be divided into a set of subsystems with the minimal mutual influence.
- The resulting set of subsystems should be used to form **a set of emergency control areas**.
- Inside an emergency control area there are technical possibilities to create an information structure for load control and data exchange among the devices which implement the proposed algorithm.
- For every controlled subsystem **a base of influence coefficients must be formed**.
- Within every controlled subsystem it is necessary to select **one coordinating device**. The device will coordinate control actions within the emergency control area.
- If coordinating device fail, **the coordination function must be automatically transferred to another device within the emergency control area**.

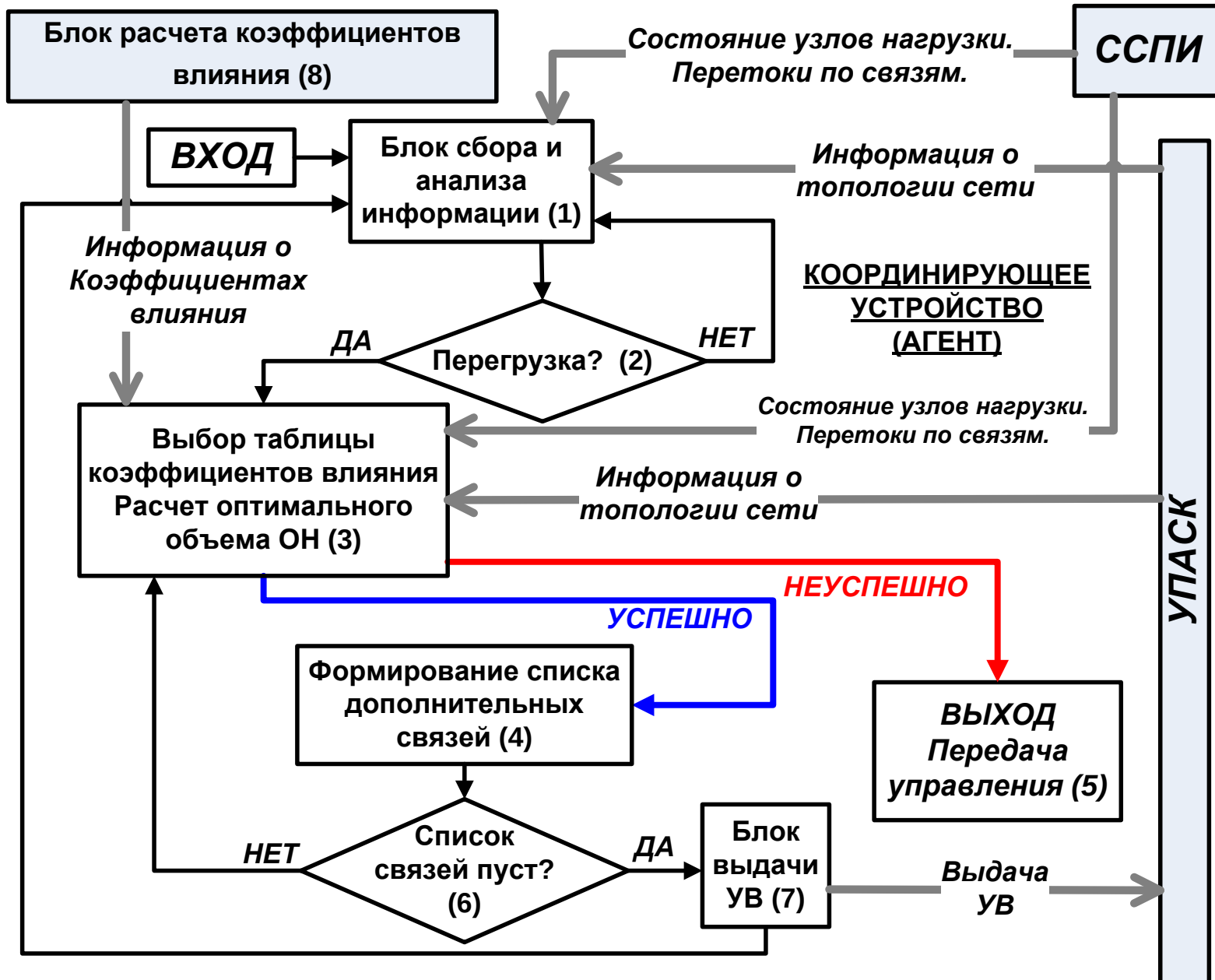
NECESSARY CONDITIONS FOR THE ALGORITHM IMPLEMENTATION



THE ALGORITHM

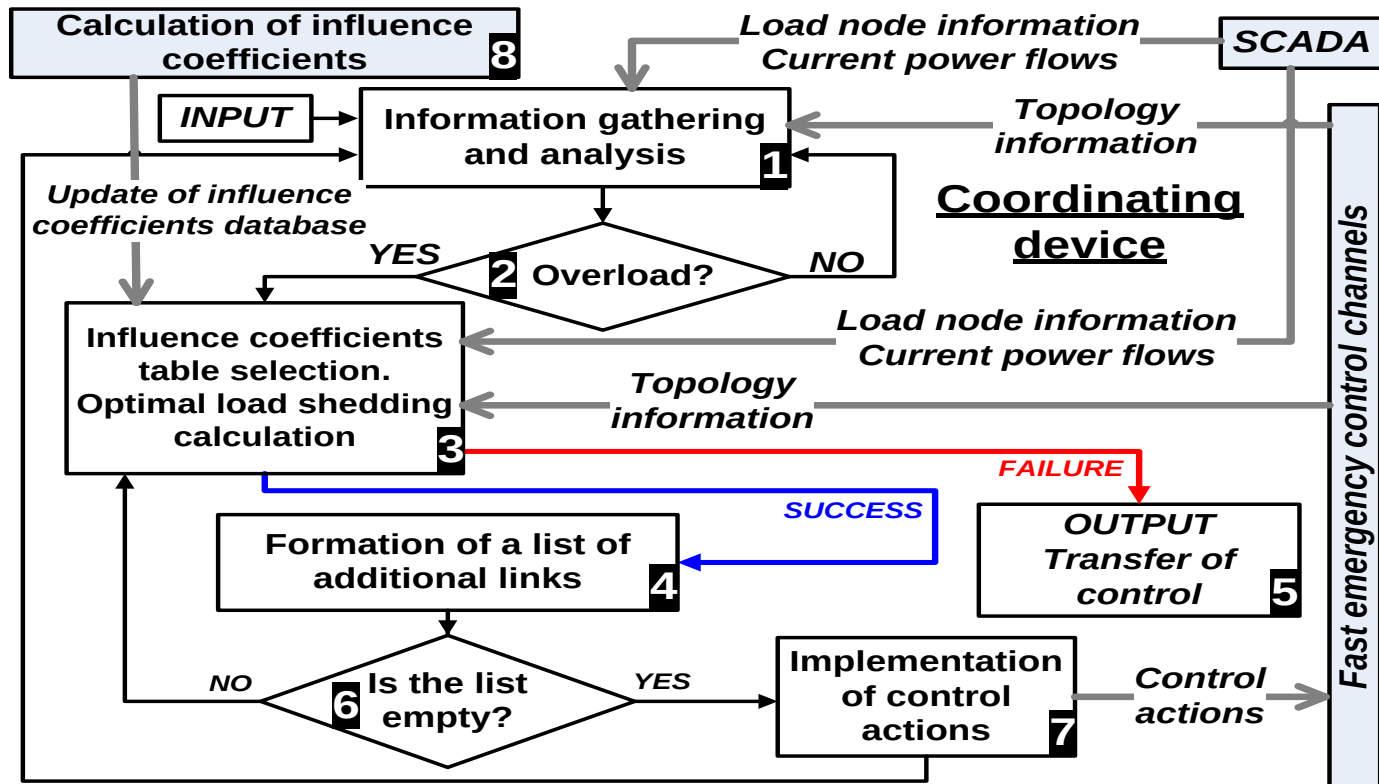


АЛГОРИТМ



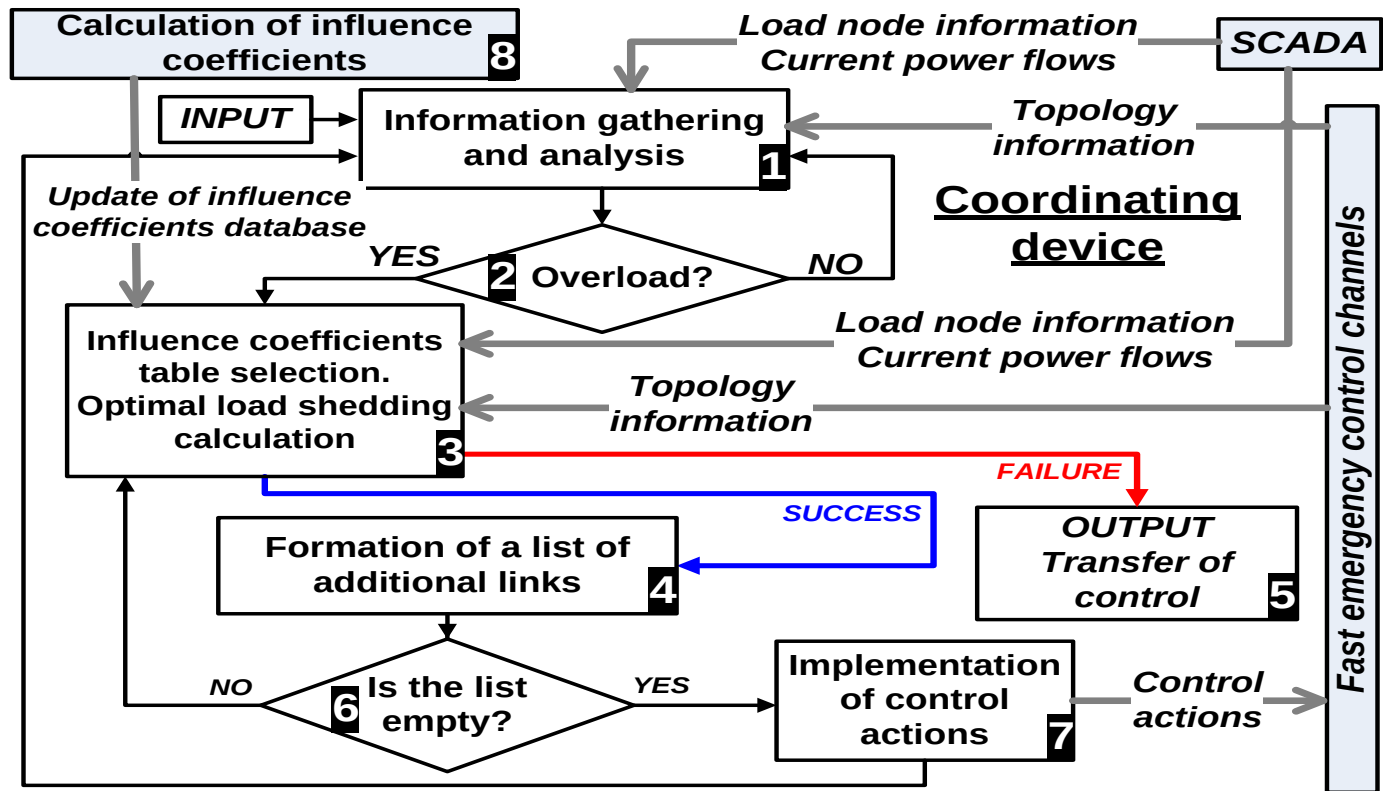
THE ALGORITHM

- In blocks 1 and 2 the load of all the links in emergency control area is analyzed cyclically. Overload is detected in two cases:
 - In the case of constant topology, block 1 receives the current information on active power flows via SCADA and detect the overloading of one or more links.
 - When the network topology changes (discrete signals from circuit breakers), block 1 calculates post-emergency power flows by the influence coefficients and detects the overloading of one or more links.



THE ALGORITHM

- If the algorithm detected overloading of one or more links, the control is transferred to block 3. **In the first cycle of the algorithm, only the overloaded links are included in a set of the analyzed links (N).** The data on the current active power flow through the overloaded link are obtained from the SCADA message, or calculated based on sensitivity coefficients. The information about the current topology of the controlled subsystem is also transmitted to block 3.



THE ALGORITHM

- Block 3 selects the table of the influence coefficients, and then calculates the control actions, by the following optimization procedure:

$$\min \sum_{i \in B} C_i \Delta P_{load\ i}$$

$$P_j^{\max} - P_j^{\text{current}} + \sum_{i \in B} k_{ij} \Delta P_{load\ i} \geq 0, j \in N$$

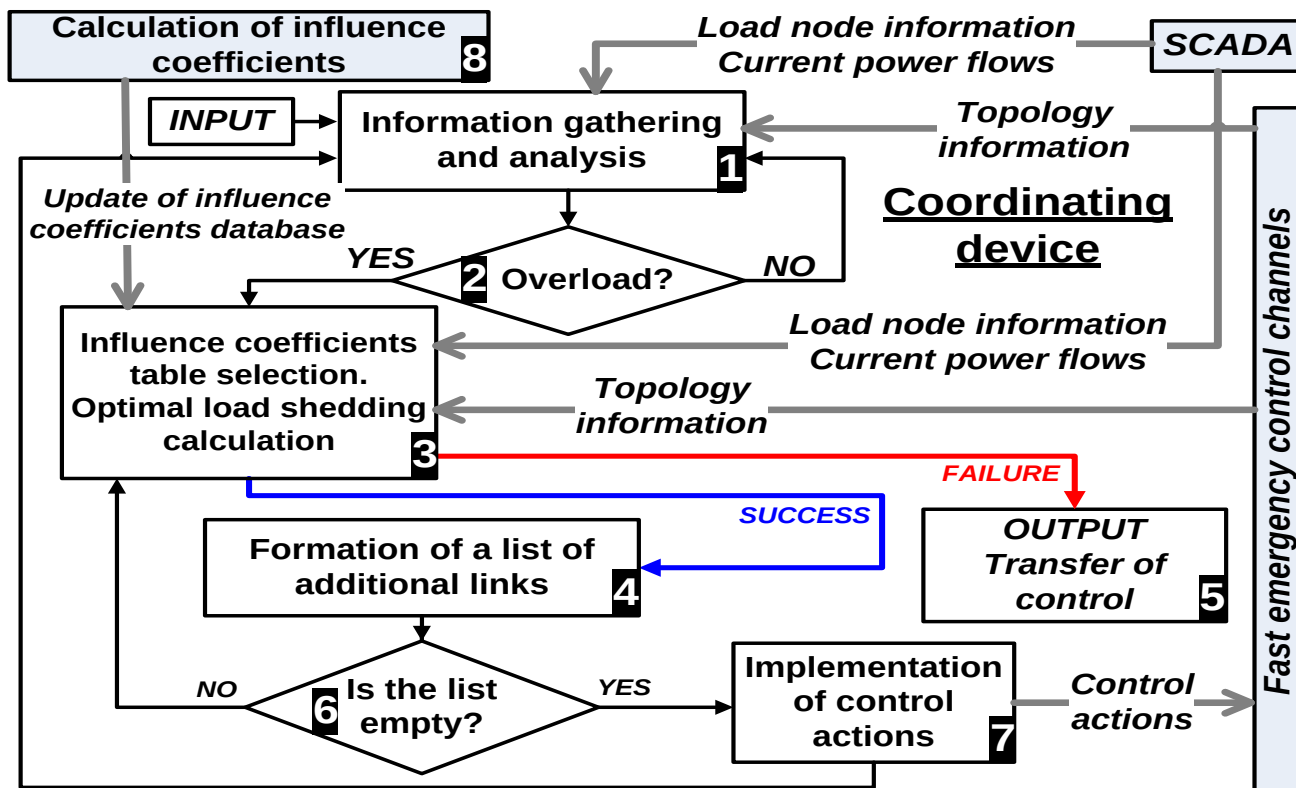
$$0 \leq \Delta P_{load\ i} \leq P_{load\ i}^{\text{current}}, i \in B$$

where - B set of load nodes participating in the work of the algorithm; N - set of analyzed link; $\Delta P_{load\ i}$ - amount of load shedding in the i -th node; C_i - weight factor determining the load shedding priority*; $P_j^{\max}$ and P_j^{current} - the maximum and the current active power flow through the j -th link, $j \in N$; k_{ij} - influence coefficient of the i -th load on the power flow through the j -th link; $P_{load\ i}^{\text{current}}$ - current value of the i -th load.

*First the algorithm will shed the load with the smaller value of C_i coefficient, i.e. a lower-priority load.

THE ALGORITHM

- The implementation of the optimization procedure in block 3 is considered unsuccessful if:
 - The algorithm fails to obtain the necessary information about the topology and/or the power flow. From this point of view the algorithm is very stable.
 - The solution to the optimization procedure is not found.
- If the operation of block 3 is not successful, the algorithm terminates and control is transferred to other emergency control devices or to the EPS dispatcher. Otherwise, creates a list of additional links which are further tested.

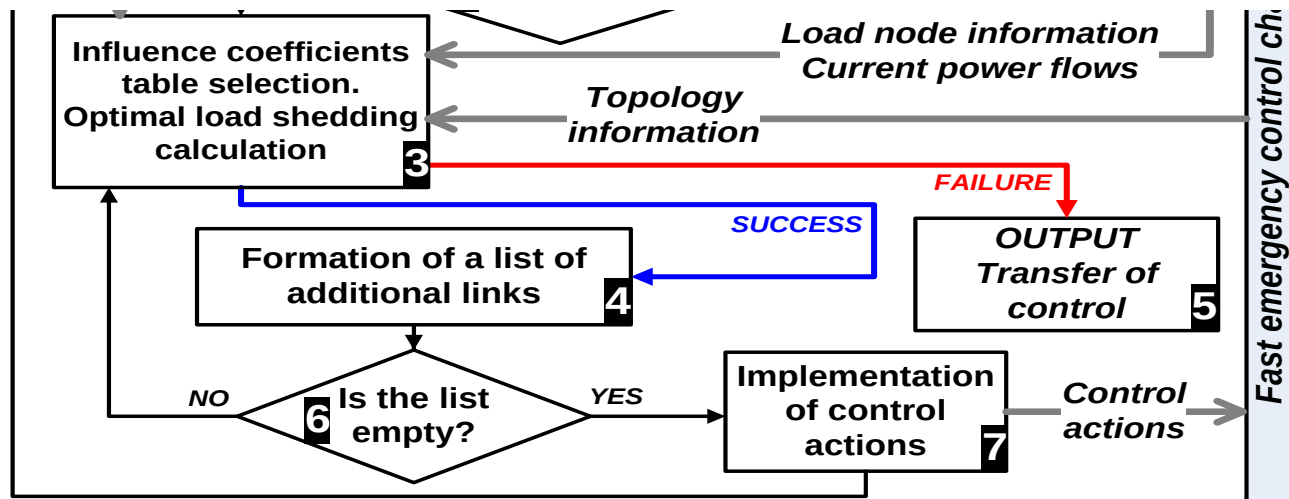


THE ALGORITHM. LIST OF ADDITIONAL LINKS.

- First, the algorithm performs the calculation of power flow changes through all links in the controlled area:

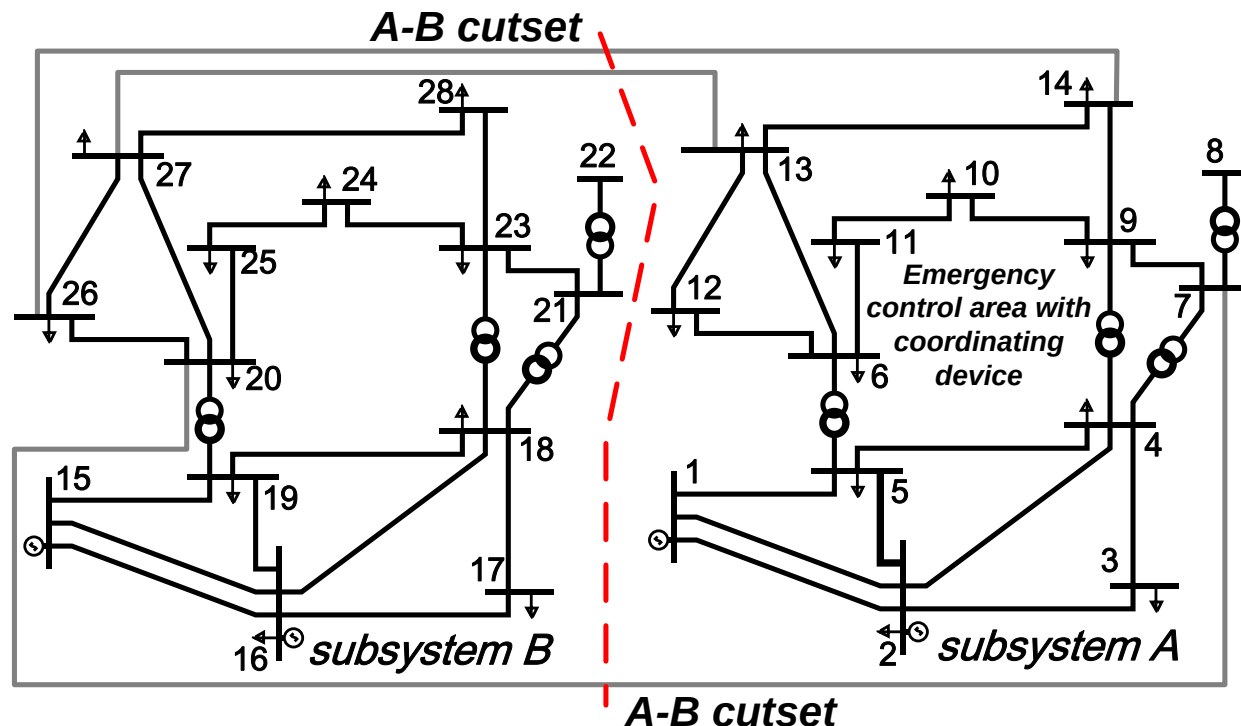
$$\Delta P_{LINE} = K \cdot \Delta P_{LOAD}$$

- A new link is added to the list (set N) if the power flow through this link increases by more than a predetermined value, and if this link has not been included in the set of analyzed links N .
- If after the analysis the list of additional links is empty (block 6), the coordinating device implements the calculated control actions (block 7), otherwise, set N is complemented by the links from the generated list (block 4) and control is passed to block 3 again.



CASE STUDY

- To study the algorithm on the example of the system with a complex topology. For this purpose, all links of the test system are switched on.
- To verify the algorithm for the case of a strong distortion of the initial state (distortion of the influence coefficients). **All calculations are performed using one set of influence coefficients (the initial state coefficients).**



CASE STUDY

- **Consider the disconnection of link 2-5** in the controlled subsystem A under the following conditions:
 - **Scenario 1. Uncontrolled subsystem B:** full network topology. **Controlled Subsystem A:** weights C_i , determining the load shedding priority, are equal.
 - **Scenario 2. Uncontrolled subsystem B:** full network topology. **Controlled Subsystem A:** high value of the coefficients C_i for load nodes 12, 13 and 14.
 - **Scenario 3. Uncontrolled subsystem B:** switched-off links 20-25, 23-28, 26-27, 15-19. **Controlled Subsystem A:** weights C_i , determining the load shedding priority, are equal.
 - **Scenario 4. Uncontrolled subsystem B:** loss of a large amount of generation. **Controlled Subsystem A:** weights C_i , determining the load shedding priority, are equal.

CASE STUDY

TABLE I. RESULTS OF THE TEST SYSTEM ANALYSIS. TRIPPING OF LINK 2-5.

N_0	$P0_{max},$ MW	$\Delta P_{LS},$ MW	$P_{CUTSET},$ MW	$\sum C_{LOAD}$	N	$\Delta P_{MODEL},$ %	$\Delta P,$ MW	M
1	36.3	112.3	14.97	112.3	2	0.29%	2.09	4 of 24
2	36.3	116.19	14.97	438.7	3	0.24%	2.33	8 of 24
3	40.35	125.27	14.97	125.27	2	0.25%	2.36	4 of 24
4	50.39	157.58	40.84	157.58	2	1%	6.53	6 of 24

Here, $P0_{max}$ – maximum initial overload; $\Delta P_{LS} = \sum_i \Delta P_{load\ i}$

– load shedding; P_{CUTSET} – initial power flow through the A-B cutset; $\sum C_{LOAD} = \sum_i C_i$ – sum of the coefficients C_i of the shed

load; N – number of iterations; ΔP_{MODEL} – maximum power flow mismatch in the nonlinear and linearized models; ΔP – maximum residual overload after load shedding; M – number of analyzed links.

CONCLUSION

- **The proposed algorithm minimizes the amount of required information and does not fail in case of noncritical data loss; thereby it provides a high level of fault tolerance.** In particular, to calculate the amount of control actions in scenario 2, we needed the information about the post-emergency power flows through 8 links out of 24. For scenarios 1 and 3, the number of analyzed links was 4.
- **A wide range of changes in the operating conditions in the uncontrolled subsystem B has a little impact on the work of automation in subsystem A (emergency control area). This also shows the effectiveness of the algorithm.** All the calculations applied a single set of influence coefficients, a set of initial operating conditions. The comparison of the calculation results for scenarios 1 and 3 demonstrates that even the tripping of 4 links in subsystem B has little effect on the accuracy of automation in subsystem A.

**Спасибо за
ВНИМАНИЕ
Thank you for
your attention
谢谢观看!**