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Principles of Protection against Blackouts in Power Systems

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Abstract— **In the work, new protection principles are proposed to form a basis for anti-collapse complexes of power systems. The principles are founded on the detailed analysis of blackouts, the response of generating sources to the deviations in emergency parameters, the analysis of existing technical solutions, and on the long-term experience in liquidation of blackouts. As a result, a conception has been created for the anti-collapse preventive complex, according to which the emergency events are returned to their optimal course, the blackouts are eliminated within some tens of seconds without personnel participation, using feasible technical solutions that are verified in practice.**

Keywords- blackout prevention, power system self-restoration, anti-collapse complex

I. Introduction

Power systems (PSs) are by their structure large technical systems comprising generating sources with technological elements of automatic control and protection as well as the transmission networks (TNs) to deliver energy to the consumers. Such a PS should have special means whose purpose would be to ensure its viability, thus resembling the living organisms, which, possessing the functions of self-organizing and self-healing, solve tasks of the kind at different levels – from cells to the central nervous system. Concerning a power system, similarity with living organisms could be seen in the use of protection means: when some elements are damaged, the protection isolates them from undamaged. One of such means is the synchronous torque of generators keeping them in joint (synchronous) operation. Unfortunately, it does not suffice for ensuring the PS viability. Despite the diversity of anti-emergency means and huge sums of money spent on the improvement of PS reliability, their blackouts persist all over the world.

For protection against blackouts, the following targets have been determined:

- in all cases to keep generating sources working;
- preservation of the carrying capacity of the TN cross-sections and automatic PS restoration to normal operating condition without personnel participation.

In the work, the results of the detailed blackout analysis performed by the authors are presented with the purpose to show the new tendencies in emergency processes, the imperfections of the existing automatics, the peculiarities of generating sources under emergency condition, etc. Based on these results, a new universal anti-collapse complex for PSs is offered, which combines **preventive short-term sectioning** (sectioning) of a power system and its automatic self-restoration to normal condition. The normal operation of the power system and its integrity is in this case self-restored within 60-100 second without personnel participation. Special additional measures are intended to help the generating sources keep operating with short-term deviations of regime parameters and to improve the reliability of a power system's self-restoration.

II. Analysis of Blackouts

To create an anti-collapse complex the in-depth analysis of blackouts was needed in order to find general indicators to which sufficiently simple automatics could respond. For this purpose it was necessary to analyze the data on 23 blackouts that have occurred since the 2nd half of the past century.

A. Classification of blackout events by stages

Based on the performed blackout analysis, the emergency processes (events) could be classified by stages as follows.

Stage 1 includes the reliability requirements for the normal operating condition that relate to the power flow limitations in the transmission lines (TLs). According to these requirements the main of which is the so-called (n-1) criterion, the disconnection of one important element of a power system must not lead to cascade-like emergency events. This means that under normal conditions the carrying capacity of network elements must in no case be fully employed, therefore the economic interests are to be restricted bearing in mind rather a rare probability of emergency. In real practice the needed analysis could be delayed; sometimes it is very hard to resist the temptation to risk due to reasons of economical benefit; all this can lead to the emergency [1], [2]. The emergency events in this time stage are very diverse.

Stage 2 is characterized by a pre-emergency operating condition when an important element is disconnected but cascade-like processes have not yet started. In this case all the means available should be used to automatically mobilize the

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reserves and to regulate the load in order to avoid emergency situation. Under new conditions the (n-1) analysis should be repeated, which would additionally restrict the carrying capacity of the transmission line. Severe hazards are created by simultaneous disconnection of several network elements. The pre-emergency condition problems are mainly solved by operative management and manual control [1], [2]. The events in this stage are complicated and diversified.

Stage 3 is reached when cascade-like processes begin, during which mass-scale tripping of the generating sources occurs that is usually followed by a blackout. As the main, the following cascade-like processes leading to blackouts should be specified (investigated in detail in [1], [3]):

Dynamic stability loss can be established within few seconds at the disconnection of an overloaded element, with power flow re-distribution among TLs that keep working. To avoid stability loss a special fast-acting protection should be used, which decreases power generation at the power sending end and increases power generation or reduces load at the power receiving end. The efficiency of generation decrease depends on the power plant's site – i.e. on the network topology. If the topology is disadvantageous, to achieve the sought-for result the decrease should be very large, which is difficult to realize. In the case of load disconnection with the help of a centralized channel at the power receiving end of a cross-section we should rely upon a "lucky chance", since the consumers' load to be shed was not known beforehand, so its size could turn out to be insufficient whereas no correction could be done at such a fast stability loss development.

Static stability loss can arise owing to incorrect consumption forecast. Such being the case, in the network where no reactive power deficit was originally observed at the active power flow rise up to the impermissible level a voltage fall begins owing to increased loss of reactive power (proportionally to the squared current). As a result, a static stability loss occurs.

Voltage instability in the transmission network [1] arises when it is overloaded with active power, which creates increase in the reactive power loss. As a result, under abnormal conditions reactive power flows appear, which create a 15–20% voltage fall. At the excitation regulators of generators responding, these latter become overloaded with reactive power and their large-scale tripping by protection means occurs, followed by stability loss. It is not the voltage fall itself but its consequences that cause such an event, and the load shedding by voltage fall indications usually does not give the desired result owing to a large territory involved.

Load rejection occurs under the influence of voltage fall at disconnection of consumers. In this case the generating sources are tripped at the load decrease below the minimally allowed level.

Asynchronous regime (out-of-step operation) is established as a result of stability loss; owing to fluctuations the generating sources are tripped, and unavoidable becomes the PS dividing into parts at the cross-sections through which the maximum power is flowing.

Multiple tripping of overloaded lines occurs when there is enhanced wire sagging up to the contact with ground, bushes and trees, followed by stabile faults. This also results in disconnection of generating sources and, finally, in PS collapse. Apart from that, to a deep voltage fall protection responds as to line faults (e.g. zone 2 and even 3 of distance protection).

The diversity of emergency events in the 3rd stage is the greatest.

Stage 4 – active power-frequency emergency (frequency avalanche) under the conditions of frequency deviations, during which stability loss of thermally-technical units occurs followed by mass-scale tripping of generating sources [4].

B. Primary and secondary emergency processes

The emergency processes mentioned above are highly diversified, and, if sticking to stereotypes, one can think that every emergency process is unique and therefore for each of them an individual protection is required. This explains existence of a great variety of protection types (their number exceeds tens), which emphasizes the problem's insolvability. However, our thorough analysis of the mentioned collapses has revealed that, even though in stages I and II (see Fig. 1) the control and, therefore, the organizational measures are mainly put in the forefront, the situations happening in stages III and IV are of radically different character. Since in these stages the personnel are forceless, the main role belongs to physical processes. When analyzing them one can notice that the first two stages are connected with others through a narrow "corridor" stage (could be designated V), in which an absolutely uniform process goes – **the overloading of dangerous network cross-sections**[2]. Fig. 1 presents the stages of blackout events as follow from the generalized results.

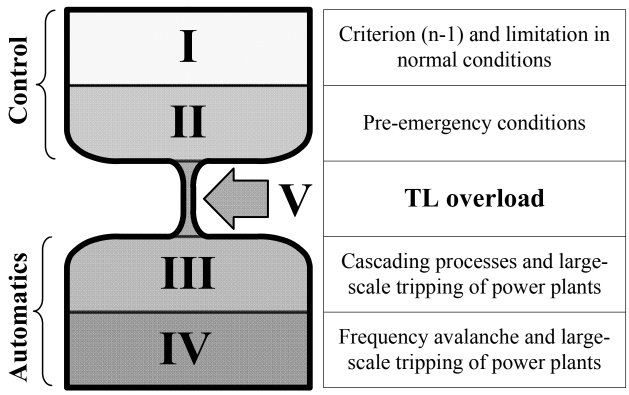

Figure 1. The stages of blackout events

[1] In some articles, instead of terms 'voltage collapse/instability' and 'frequency instability' the authors use 'voltage avalanche' and 'frequency avalanche', respectively, to stress that a large quantity of similar processes happens within a short time in a significant part of a power system.

[2] To dangerous network cross-sections we assign TL complexes that combine the PS parts with power flows exceeding the maximum admissible. Such dangerous cross-sections are known to the personnel; they are equipped with control devices and receive especial attention. As dangerous we consider overload that is capable of creating stability loss, voltage avalanche or unallowable wire sagging. This can be identified based on the calculations using a mathematical model of the power system

Although the first two stages are also of importance, while designing the anti-collapse protection we should concentrate upon the character of physical processes and the technical means of protection.

Now it is necessary to answer the question: what would occur if the emergency TL overload was eliminated? It is clear that in this case cascade-like processes could not arise and the PS reliability level qualitatively would improve. When considered from this standpoint, the emergency events could be classified into primary (cause) and secondary (consequences) as shown schematically in Fig. 2.

Quite natural is that the primary event causing secondary ones is the emergency overload of dangerous TN cross-sections. It is easy to verify that all the currently applied protection means are directed towards elimination of secondary processes. The question as to which of them needs the strongest protection is purely rhetoric. It is clear that the protection should be directed against emergency overload of transmission network. In this case it should be clarified how it is realizable physically and what devices could be used for this purpose.

III. Radical Means for Elimination of Overload

The protection of TN lines against emergency overload can be provided by acting on the load at the power receiving end, since the power generation decrease at the power sending end turns out to be inefficient due to the topology; besides, after such impact on power plants fast restoration of power production is often impossible. On the overload protection definite requirements for speed of response and precision should be imposed. The high speed of response is especially important for protection against emergency in the cases of dynamic stability loss in a power system, since such a loss proceeds within 1 second. In other cases, when overload occurs under stationary conditions – e.g. in the cases of erroneous load estimation – the protection can respond with a delay of several seconds.

As a solution to the problem the authors propose using **preventive short-term sectioning**, which instantaneously liquidates the overload by isolating the deficient region [5]. The sectioning can be considered optimal if it is performed at the place through which the power close to degree of overload (the difference between the overload and the desired load) is flowing, so the network cross-section will be released keeping its carrying capacity at work. For overload protection, at PS sectioning all the lines of the dangerous cross-section, which could be spaced far apart, should be simultaneously disconnected. Therefore it is necessary that the protection be centralized. Taking into account that the instantaneous action of the protection is often used, it is important that the information be received through fast-operating logic signal channels. The numerical information should be prepared beforehand, under normal regime.

The analysis of protections against secondary emergencies [2] evidences that in these cases a centralized protection with a matrix structure meant for stability loss prevention is suited best.

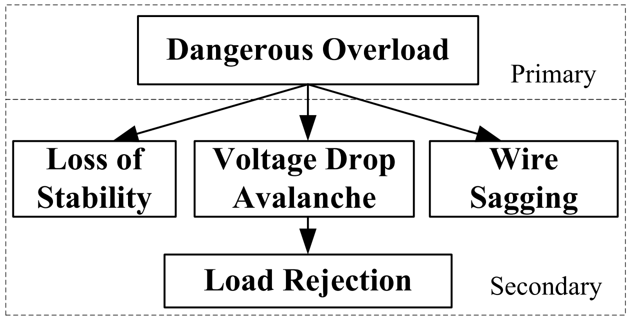

Figure 2. Primary and secondary emergency events

Such protection, at a corresponding regime severity parameter and responding to the signal about tripping of a TN element, sends a control dose for tripping the generators of power plants or fast-valving of turbines by the electro-hydraulic control system at the power sending end of the cross-section [6]. To eliminate the TL overload, the mentioned matrix structure could be used not for action on a power plant's capacity but for PS sectioning at the power receiving end, taking as a pair of parameters the regime severity level and the signal for an element's tripping (see Fig. 3) [5].

The former parameter mentioned is the power flow through a dangerous cross-section as the indicator of the regime severity. The latter is the signal about an element's tripping, which arrives through a fast-acting logic channel.

The matrices correspond to a definite structure of a network's cross-section – a matrix is changing with changes in the PS scheme. As concerns the addressing principle, the action must be addressed to the circuit-breaker for switching it off at the sectioning place. The starting point for a protective action is the emergency line disconnection at a controlled cross-section.

As a result of sectioning, at the power sending end a power rejection will occur, which in the optimal case will be equal to the network overload. The slightly changed frequency will be set by the turbine governors and their secondary control (setting variation system). In turn, at the power receiving end an as much as great load surge will be observed. Since at this latter PS part the thermally-technical units cannot rapidly assume the load (even if there is reserve), the power deficit will cause a frequency fall, which will precisely be liquidated by the under-frequency load shedding automatics (AUFLS).

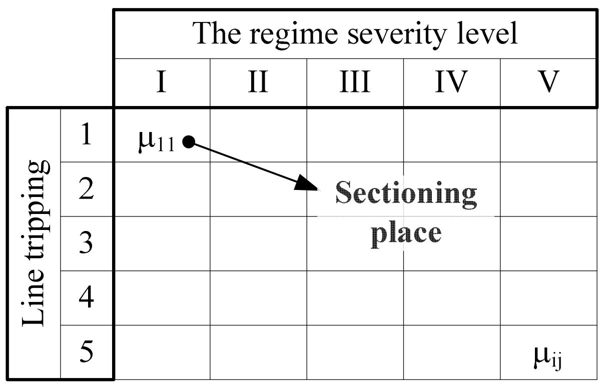

Figure 3. Control action matrix

Undoubtedly, disconnection of consumers could be a disadvantage; however, this problem is to be solved at restoration of PS integrity, using the self-restoration mechanism, in short-term (1-1.5 min) transient processes.

A. Recognition of overload and determination of the sectioning place

To fix the moment of the beginning of an emergency event the real-time mathematical model could successfully be used, which would perform several tasks (the programs are mostly developed and used for some other purposes of a power system) [7], [8]:

- regime estimation (elimination of measurement errors included);
- determination of the maximum allowable power flow through dangerous cross-sections under real condition, observing the (n-1) criterion at tripping of a PS element;
- obtaining of instructions under pre-emergency conditions when urgent measures must be taken to avoid a cascade-like emergency development;
- since dangerous cross-sections are known beforehand, power flows through them are controlled automatically, with the overload level determined before, under normal condition, in dependence on the real power flow at disconnection of different lines and storing the action type in the memory.

To each disconnection that causes dangerous overload in the network under a particular regime there corresponds a definite sectioning place, which is fixed as the optimal sectioning address under emergency conditions [9]. The sectioning optimality can be provided by controlling the power flows under normal conditions in the possible sectioning places. The sectioning should be performed at the place through which the power is flowing that is close to the TN cross-section overload.

The following aspects should be taken into account when choosing the optimal sectioning place: 1) minimization of the consumers' power to be tripped, which is achieved if the sectioning occurs with load shedding corresponding to the degree of network overload (equal to the difference between the overload and the desired load); 2) possibility to start the mechanism of automatic self-restoration, which is ensured by separating the power-deficient region; this is sufficient for frequency decreasing to the level necessary for putting the first automatics stage into operation.

B. Protection solutions for overload elimination

Several solutions can be offered by the authors for overload elimination by protective means. Priority should be given to those using mathematical model calculations as little as possible, being more oriented towards the digital signals from local PS elements and fast-acting logic channels for these signals (Fig. 4).

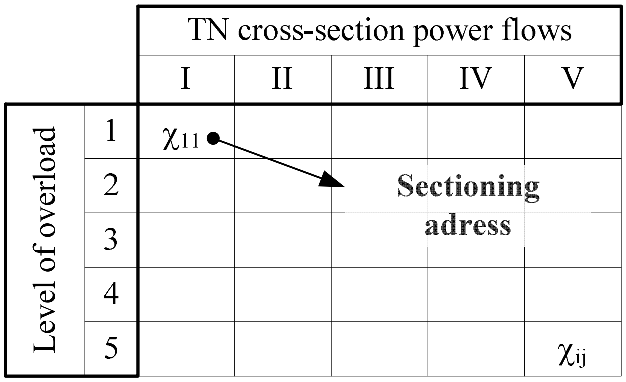

Figure 4. A sectioning matrix

In this situation only a signal about the severity of a TN overload is needed, which arrives through a corresponding logic channel. To each overload level the cross-section corresponds where the sectioning should be performed.

This done, both the dynamic stability loss and the possibility of voltage avalanching will be eliminated. The presence of such a signal means that there is threat that overload would cause the dynamic stability loss, so the protection must act instantaneously. At the same time, if this signal is absent then a voltage avalanche could be expected, so the protection, for greater reliability, can act with a time delay, since the overloaded generators would be tripped within 10-20 seconds.

It is possible to eliminate the TL overload in a simpler (non-optimal) way. In this case one-end disconnection of an overloaded line is performed at a fixed place of the power receiving end of a power system. This would lead to the creation of a greater power deficit in this part, so a greater consumers' load is to be tripped. In this case the sectioning place is not changed, and the action's addressing through a branched logic channel becomes of no use, which simplifies the protection system. Such non-optimal emergency liquidation should be considered as possible, especially in a large power system where the deficit is incomparable with its capacity (for example, in a PS whose capacity is 200GW a disconnected line's power of 10GW would make only 5%).

IV. Paradox as a Means for Self-Restoration of a Power System

The appearance of the self-restoration mechanism should be dated back to 1963, when one of the authors of this paper, Jekabs Barkans, worked as the chief operator of the Latvian Power System. At those times there were, almost every year, PS faults (in the form of frequency fall emergencies) caused by power deficit and weak TN interconnections. From quarterly emergency circulars issued by the USSR Energy Ministry it was clear that the situation everywhere in the former Soviet Union was the same. Having analyzed the emergency events, J. Barkans revealed that all emergencies of the kind already then possessed identical character, which led him to the idea to complement the existing fast-acting AUFLS with the following three elements [10]:

1. slow-acting AUFLS[3] for restoring the frequency, consisting of several stages with various time delay settings (e.g. 8-10, 15, 20, 25 s, and so on) and with a high setting for start (similar to the first stage setting of the fast-acting AUFLS), which serves for changing the retiming setting to the rated frequency after the start. This slow-acting load shedding automatics begins its operation of restoring the frequency up to the normal level after the fast-acting AUFLS has been completed its operation (see Fig. 5);
2. automatic synchronization, which at close frequencies is performed by the synchronism check devices already existing in all TLs. The switching-on of the first line proceeds in the synchronism-catching mode (which was possible owing to the frequency uniformity), after which, by the indication of synchronism, the re-connection of other TLs follows. Thus the integrity of the PS is restored;
3. automatic reclosing (AR) of consumers' lines with control of frequency variations by the normal frequency indication within a given time interval.

All the offered complements were implemented using local means (AUFLS, AR etc.) – mutually independent but linked through the PS operation thus ensuring a high PS reliability. This idea was implemented on the system scale in 1964. Since that time all the frequency emergencies (20 events of the kind) have been self-liquidated within approx. 100 seconds. Publication [10] that turned out to become a subject of consideration at the mentioned Ministry was used to include its main points into Directive Anti-Emergency Instructions, which ensured the wide implementation of this development into other power systems of the former USSR.

During exploitation of the proposed self-restoration mechanism two its important qualities have been revealed:

First, since emergency self-liquidation takes 1-1.5 minutes, for the majority of consumers the process remains unnoticed, since they are adapted to the cases (on the average 15-20 times a year) of contactors' switching-off when in the network short-circuit occurs caused by voltage fall. The same by appearance is an automatically liquidated frequency emergency process.

Second, a frequency fault in a paradoxical way from a dangerous PS emergency becomes a tool for restoring the power system to normal condition. A situation arises that resembles a chess game. Indeed, it is known that an experienced chess-player, unnoticeably, by a series of skilful attacks and resourceful defence, is directing the situation to the technical position with forced winning. A similar situation is with a frequency fault. If earlier it was perceived as a power system's "infarction" or "insult" with inevitable collapse, now, owing to the self-restoration mechanism, it is not anymore the stone for a drowned man but a ring-buoy that allows him to emerge happily. For a power system this means that it is possible to disrupt an emergency situation at its very outset and to restore automatically the normal condition provided that the process goes in the required direction.

[3] Slow-acting AUFLS is widely employed in the power systems in the territory of the former USSR; in those of USA and EU the frequency restoration process is mostly controlled manually

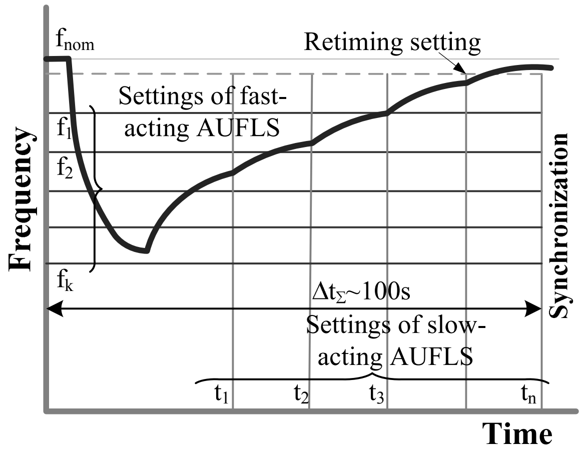

Figure 5. Frequency variations in the deficient region

A. *Deficient PS part*

Elimination of the TL cross-section overload by sectioning allows, first of all, islanding the deficient region (under the pre-emergency operating conditions) before the development of cascade-like processes thus ensuring that the generating sources are kept at work. Second, the overloaded TL cross-section is kept operating, being unloaded to the desirable level. Third, the splitting and the automatic self-restoration of PS normal conditions proceed in seconds (60-100 s).

The frequency changes in time in a separated region are shown in Fig. 5 (for more details see [2], [3], [4]). In the beginning, frequency is falling owing to the active power deficit. The load shedding automatics, responding to the frequency fall (or its variation rate, i.e. derivative), stops it. Owing to the delay time of the automatic device, during its action some extra stages can operate disconnecting additional consumers' lines; as a result of power surplus the frequency slightly increases (remaining at a reduced level). The frequency restoration up to the normal level is performed by the mentioned slow-acting AUFLS, and the success is ensured by the retiming setting at the nominal frequency value thus preparing the split region for automatic synchronization.

Up to now, in many power systems the restoration of normal frequency and of a PS's integrity is entrusted to the personnel. This retards the emergency liquidation and can even result in repeated emergency processes. To eliminate the personnel's participation in the process it is important to use the self-restoration mechanism.

The operation of a power system at a reduced frequency negatively affects its equipment. Therefore it is very important to keep the generating sources in operation. As relates to the steam power plants, this problem is solved with the help of fast AUFLS; in turn, for gas turbines and nuclear plants specific measures to be taken by frequency fall indication should be provided. Also, to control the distributed generation special standards for protection automatics are necessary [4].

To summarize, if the AUFLS settings – taking into account the possible rate of frequency variations and level of load relief - are chosen correctly, the frequency would not go out of the range allowed for power plants.

B. PS part with power surplus

In order to perform synchronization successfully, it is necessary to achieve as low frequency difference as possible in separated PS parts. In some cases, due to unforeseen contingencies, the frequency in a power system's surplus part could be slightly higher, which would retard the synchronization. Such being the case, in this PS part a forced secondary frequency control could be used in order that its nominal level be reached faster [2], [8].

C. Reintegration of a power system

Despite the implementation of the self-restoration mechanism it has not been examined completely. Therefore in some cases it is necessary to perform automatic re-integration of a PS using a simplified synchronization, which would proceed at an uncertain place under uncontrolled conditions. This process requires synchronization equipment. Unfortunately, this concerns not only power plants. As known, on the lines there are three-phase automatic reclosing devices. At one end the lines are reclosed by the voltage absence indication, whereas at the other – by the synchronism indication using the corresponding synchronism check devices.

Taking into account that emergencies in power systems occur rarely enough, such non-optimal synchronization is allowable. In works [11], [12], [13] the synchronization process and the factors affecting it are considered in detail, and the relevant mathematical model to calculate such a process is presented. As the main factors of successful synchronization the following could be mentioned:

- a sufficiently small difference of frequencies and the acceleration provided by the above mentioned slow AUFLS;
- a comparatively small switching-on angle provided by the mentioned settings of a synchronism check relay (for example, +40 with a 1s time delay, see Fig. 6).

To verify the feasibility of using the synchronism check devices it is necessary to analyze the process applying the mentioned mathematical model [13]. In the case of successful synchronization after switching-on, the angle in the transient process would grow up to the maximum value, $\delta_{\max}$, and, with the fluctuations attenuated, a synchronous condition will be achieved (Fig. 7).

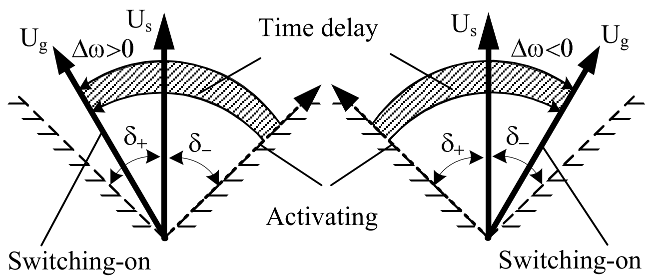

Figure 6. Working zone of a synchronism check device

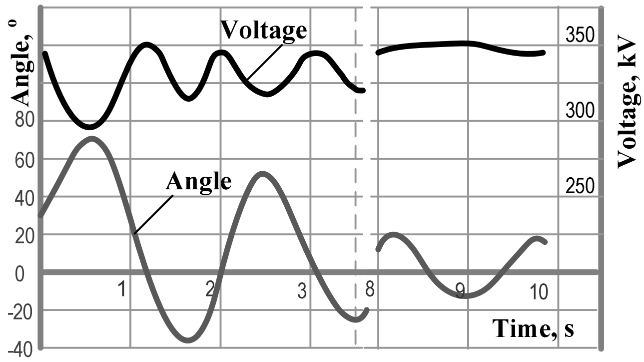

Figure 7. Transient process of successful synchronization

In this case the switching-on current is not exceeding 30% of the short-circuit current, and, from the viewpoint of voltage reduction, the maximum angle is not exceed allowable in the transient process.

D. Restoration of power supply to consumers

After the PS integrity has been restored, the consumers' lines are reconnected with the help of automatic reclosing by the normal frequency indication [14].

The integrity of a power system (or its carrying capacity) might be not restored if in transmission lines there is stabile damage. To avoid a repeated frequency fall under the conditions when synchronization has not yet been reached, the power supply to consumers should be performed step-by-step (see Fig. 8).

After the first time interval t_{AR} if frequency was higher than f_s, reconnection of the first consumer group will take place. The AR by normal frequency will perform frequency control, and, if it keeps the value higher than f_c, the consumers remain connected. After some time (~6s) the next stage operates, and so on. In the case the frequency decreases below the setting value, the consumers' reconnection will be halted or pass to the waiting mode.

Owing to the frequency control, the threat of repeated frequency emergencies or voltage fall avalanches in a separated region is completely excluded.

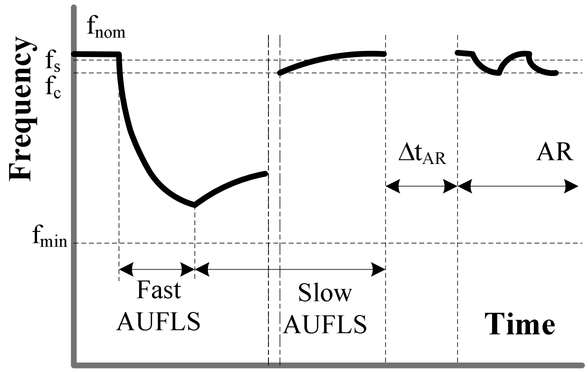

Figure 8. Frequency variations at AR operation after unsuccessful reintegration

V. Blackout Elimination as a Fast Cyclic Process

From the above consideration it follows that the anti-collapse protection is a complex consisting of elements that prevent development of blackout in a power system and restore its normal operation without personnel participation.

This process is therefore of cyclic character (see Fig. 9).

Accordingly, the protection elements can be grouped as follows.

- preventive (warning) – the key protection element is fast-acting protection (I) against the network cross-section overload performed by short-term PS sectioning at pre-defined places, which instantaneously eliminates the overload by isolating the deficient region;
- localizing – in the deficient part the fast-acting AUFLS (II) will operate, and the frequency for some time will remain at the reduced level allowed for power plants;
- restoring – in the deficient part the slow-acting AUFLS (III) restores the frequency up to the normal level; in turn, in the power surplus region the frequency normalization occurs owing to the operation of turbine governors, and, if necessary, for accelerated synchronization a forced regulation (IV) is used; by synchronization (V) the PS integrity is restored; by the normal frequency indication automatic step-by-step reconnection of consumers' lines (VI) takes place (in ~20s at the normal frequency indication).

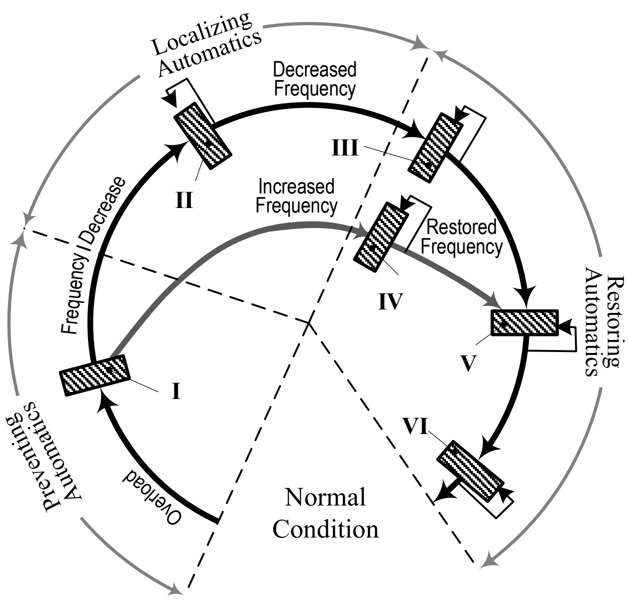

Figure 9. Joint operation of protection devices: I – elimination of cross-section overload by short-term PS sectioning without feedback; II – operation of fast AUFLS; III – operation of slow AUFLS; II and III operations proceed with feedback providing higher reliability; IV – forced control; V – PS reintegration by synchronization; VI – automatic reclosing of consumers' lines

As the result of operation of the proposed anti-collapse complex a blackout is to be liquidated. Generally, such complex fulfils the PS self-restoration function and meets the following requirements:

- to perform as a radical protection means against network cross-section overload;
- to be capable of operating quickly when fulfilling preventive functions;
- to achieve that after optimal sectioning the previously overloaded network cross-section keeps working, using its carrying capacity as much as possible;
- at the use of the already existing protection means for new purposes the psychological aspects of implementation should be observed;
- the protection should contain a self-restoration mechanism, which, while restoring the PS normal condition without personnel participation, makes this process unnoticeable for the majority of consumers;
- to be capable of operating at a control precision that might be not very high.
- as much as possible to give preference to local devices (AUFLS, AR and so on), which would ensure higher reliability.

To achieve that the protection operates automatically, it must be kept ready for work. For this purpose in a joint power system an analytical centre should be created, which would be empowered to dispose protection devices, their number and settings.

VI. Conclusions

Analysis of the processes going at a PS blackout has made it possible to reveal their systematic feature to which a simple anti-collapse complex can respond. As the primary indicator of a blackout the TN cross-section overload is used. The instantaneous liquidation of the primary cause prevents the development of secondary causes (cascading processes) of the blackout, thus allowing the generating sources to be kept at work and raising qualitatively the reliability of PS operation.

For elimination of the overload, PS is sectioned with separation of the deficient region; as a result, the overloaded TN cross-section is unloaded, thus allowing the use of its carrying capacity to the maximum degree; in turn, in the islanded region the power deficit, causing a short-term frequency fall, activates the PS self-restoration mechanism.

Operation of this mechanism results in the frequency normalization in PS parts followed by their synchronization at a small frequency difference using the existing on the lines synchronism check devices and, after that, by re-closing of consumer supplying lines at the normal frequency indication. The blackout elimination proceeds automatically, fast (within approx. 100 seconds) and without personnel participation, so the majority of consumers have no time to realize the threat of a blackout.

To avoid difficulties associated with implementation, for the proposed anti-collapse complex the devices are chosen which have been verified in practice and used for other purposes – that is, which need the least improvements.

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VIII. Biographies

Jekabs Barkans (Prof., Dr.Habil.Sc.Ing) received the Doctor degree in Power Engineering from the Riga Polytechnic Institute (RPI), Riga, USSR in 1963 and the Doctor Habil. degree in Power Engineering from the Power Engineering Institute of Academy of Science, Moscow, USSR, in 1975.

His employment experience includes: a deputy chief operator of the Latvian Power System, 1953-1962, and the chief operator in 1962-1979. He worked as a docent at RPI in 1964-1979 and since 1979 he has been working as Professor at the Institute of Power Engineering, Riga Technical University (RTU). In 2000 he became Emeritus Professor.

His area of research and teaching activities are the power quality control, voltage and reactive power control, automatics of blackout prevention and self-restoration of power systems. He was a State price laureate in 1970. He is the author of 17 books and 60 patents.

Diana Zalostiba (S'2007) received the M.Sc. first-class honors degree (with distinction) in Power and Electrical Engineering from the Riga Technical University, Riga, Latvia, in 2005. Currently, she is pursuing a PhD degree at the Power and Electrical Engineering Department of the RTU.

Now, she is a Researcher at the RTU. Her research interests include the prevention of blackouts of power systems, and the self-restoration of power systems. Diana Zalostiba won the Werner Von Siemens Excellence Award in 2005. She is the author of 2 patents (with Prof. J. Barkans).