Arrangement of the Krško NPP Protection Scheme for the Power System Malfunction Cases

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ABSTRACT. The Krško NPP has been designed with the capability to reject 100% of its rated power and runback to the station electrical load. However, an adequate detection system of the outside network degradation is needed for the activation of the existing load drop anticipated (LDA) function.

The Krško NPP electrical, turbine and generator protection systems were carefully evaluated in order to redesign some of its functions. These additional functions should be able to protect and disconnect the plant from the system whenever some serious trouble of the outside electric power system is detected. On the other side, preventive measures should be introduced to avoid unnecessary plant disconnection or unnecessary power system collapse due to such disconnection.

At the end, the paper presents a precise design of additional function possibilities for the Krško NPP electrical protection system. A critical evaluation of these functions is given and the best option is proposed.

1. Introduction

Following the Krško Nuclear Power Plant (NPP) Investor’s request, the plant has been designed with the capability to reject 100% of its rated power and runback to the station electrical load. As a result, the load drop anticipated (LDA) function is provided by the plant supplier. The LDA function activates corresponding turbine controls based on its overspeed signal, obtained after the load rejection by the 400-kV switchyard breaker opening. The loss of the off-site power or power system degradation signal should be served for the switchyard breaker opening. Recognition of the mentioned power system malfunction is left to be arranged by the local utilities standard practice.

The Krško NPP is connected with the 400-kV transmission network of the electric power systems (EPS) of Slovenia and Croatia. The plant is sited at the very boundary of the two systems. At the same time, the double 400-kV transmission line from the Krško NPP towards Zagreb constitutes the interconnection with the neighbouring EPS of Croatia and potentially also with other systems on the territory of the Balkan. The Krško NPP is connected with the Slovenian EPS through the 400-kV Krško-Maribor line. To assure operation in the post-contingency states, that may occur in EPS, each NPP should be connected to EPS
through a number of connections. The Updated Safety Analysis Report (USAR) [1] of the Krško NPP foresees that EPS should operate so that failures in one of its sections would not endanger operation of the plant over another part of the system. The analysis of our experience with interaction of the Krško NPP and external EPS operation shows certain facts that sometimes differ from expectations.

As a result of the recent plant trip [2], and upon the Krško NPP request, a careful examination of the existing protection system design and possibilities of an additional detection feature of the power system degradation was made in document [3].

2. **Electrical protection systems and on-site power supply**

Fig. 1 shows the Krško NPP on-site power supply. During the regular operation, the generator supplies over unit transformers T1 and T2 the on-site power supply and over main transformers GT1 and GT2 the network.

![Diagram of Krško NPP on-site power supply and protection systems arrangement](image)

In case of the 400-kV network disconnection, the on-site power supply is assured from the generator over the 21-kV load breaker and unit transformers T1 and T2. During the shut down, the on-site power supply is provided from the 400-kV network over the switchyard breaker and transformers GT1, GT2, T1 and T2. In case of the generator-transformers unit failure, the on-site power supply is facilitated from the 110-kV network over station auxiliary transformer T3.

The above described design of the Krško NPP on-site power supply results from the Investor’s request that the Krško plant should remain on the on-site power supply in case of
the 400-kV network trip, and request imposed on nuclear power plants specifying that the on-site power supply should be provided by two independent external sources.

The action of the generator primary protective relaying lockout relay 86G, and generator backup protective relaying lockout relay 86U disconnects the 400-kV breaker in the transformer field and switches the on-site power supply to the 110-kV network. The load breaker being foreseen solely for the rated current disconnection and should remains connected. Executive relays 86G and 86U are protections of the generator-transformers GT1, GT2, T1 and T2 unit (generator differential, generator ground overvoltage, phase balance, directional power, T1, T2 φA, B, C transformer differential, GT1, GT2 transformer fault pressure, φA, B, C generator differential, T1, T2 transformer fault pressure, GT1, GT2 time overcurrent, T1, T2 overcurrent, GT1, GT2 ground relays time overcurrent, distance).

The action of the generator control protective relaying lockout relay 86GC opens the 21-kV load breaker and the on-site power supply is supplied through the 400-kV network. The 86GC operates in case of the generator loss of field, stator water cooling failure, excessive V/Hz and overexcitation.

The turbine is protected against the overspeed with the overspeed controller (OPC), mechanical and electrical speed protection and load drop anticipation (LDA).

In case of a too low voltage on safety buses, a blackout occurs resulting in the reactor trip and connection of the on-site power supply to the Diesel generators. In case of a too low voltage or a too low frequency on servicing buses, reactor trip takes place.

The 21-kV load breaker opens at the 86GC protection operation, turbine trips, thrust bearing trip device actuates and reactor trips, if the latter has not tripped due to the 86G and 86U trip.

The 400-kV switchyard breaker opens in case of operation of 86G, 86U, bus protection and protection prior to the circuit breaker failure.

3. External power system malfunction detection possibilities

After the Krško NPP 400-kV switchyard breaker trip, i.e. the plant electrical load rejection and turbine speed raising, the turbine OPC and LDA functions become active. The functional diagram of the OPC and LDA logic is shown in Fig. 2. The OPC function becomes active when 103% of the turbine speed is exceeded while the LDA function is activated immediately after the 400-kV breaker trip resulting on the extensive plant power reduction, just for its own electrical supply.

As shown in Fig. 2, only the 400-kV bus protection signal activates the LDA function. Currently, there is no special protection feature for the external power system malfunction detection. Following the above, two questions remain to be answered:

- Why there has been no such protection logic installed?
- What were the original reasons for the LDA function request?

Indicative answers to the above questions have been obtained, conclusions were taken and solutions proposed. Namely, at the time when the Krško NPP construction contract was prepared, the external power system was very unreliable ex-Yugoslavian EPS in isolated operation. During the plant final design and construction, the external power system was interconnected with the very reliable UCPTE interconnection. The original reason for the LDA function implementation thus vanished and it is probably due to this fact, that the appropriate protection logic was not included.
It is not an easy task to generate an effective detection of the EPS malfunction as the selectivity of such feature should be 100% certain. The best functional solution is shown schematically in Fig. 3. Following Fig. 3 proposal, the system malfunction signal is generated via a complex computer expert system decision program, based on a wide area power system data collection. It is obvious, that a practical solution of such proposal would be very complex and extremely expensive.

Speaking in terms of the power system degradation, the underfrequency is a reliable method to detect the network problem. It is typically used to provide the trip function for the plant switchyard breaker. However, EPS operating with the very reliable UCPTE interconnection is not frequently affected by frequency variations, and the last Krško NPP trip case [2] shows, that the network frequency can not be the only indicator of the EPS problem.
4. Network problem indication proposal

Taking into account the fact that the 400-kV switchyard breaker switching effects the Krško plant two main functions, namely

- connection to the external EPS and to an electrical load for the produced plant energy,
- primary source of the electrical supply for the plant local electrical load,

the protection logic for the 400-kV breaker trip should be designed very carefully avoiding the generation of the unnecessary trip signal.

On the other hand, many of the plant trip functions are realised via the 21-kV generator load breaker, i.e. the OPC function. There exist a danger that the turbine trip can open the 21-kV load breaker under external network problems and generator heavy current loading, as described in ref. [2] trip case.

In order to detect external network problems in the selective sense and to prevent the 21-kV load breaker to open under heavy current conditions, the additional 400-kV switchyard breaker trip logic is proposed, as shown in Fig. 4. The network voltage and frequency measurements are used to detect the external EPS malfunction, and the generator speed and current signals are used to prevent the 21-kV load breaker opening under the heavy current condition.

Fig. 4. Practical solution function diagram of the 400-kV system malfunction detection

The external network voltage and frequency measurements are made very carefully with the target of assuring selectivity of the trip logic. Namely, the external network protection system (the distance protection system) and the undervoltage and underfrequency plant trip logic already exist (RCP motor undervoltage and underfrequency protection - reactor trip).
The proposed additional trip logic from Fig. 4. should be activated before the plant electrical load protection system trip takes place and after the external network distance protection system is activated.

5. Conclusion

The size and reliability of the Krško NPP external power system have considerably changed from the time of the plant contract preparation to the time of the plant construction and thereafter. It is probably for this reason that the plant LDA function protection logic (400-kV switchyard breaker trip logic) has not been developed completely.

An additional 400-kV switchyard breaker trip logic is proposed in [3] and Chapter 4 in order to detect external power system degradation. The protection logic is activated upon the network undervoltage and underfrequency time dependent trip signal, as well as upon the generator overspeed signal under the heavy current condition. Since

- the external power system under present conditions is very reliable,
- the plant turbine executive actions of the LDA function are not effective in accordance with the plant design (the 100% load rejection and runback to the plant electrical load have never succeeded), and
- the 400-kV switchyard breaker serves as a gate to the plant external electrical load, as well as the primary electrical supply breaker of the plant local load,

the installation of an additional 400-kV switchyard breaker trip logic is possible, but not recommended.

References

7. J. Ioannidi: STR NEK 95-010 Load Rejection and Runback to Station Electrical Load, Gilbert/Commonwealth, Krško, 1994