International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:5, No:2, 2011

Re-Design of Load Shedding Schemes of the Kosovo Power System

A.Gjukaj, G.Kabashi, G.Pula, N.Avdiu, B.Prebreza

Abstract**—**This paper discusses aspects of re-design of load-shedding schemes with respect to actual developments in the Kosovo power system. Load-shedding is a type of emergency control that is designed to ensure system stability by reducing power system load to match the power generation supply. This paper presents a new adaptive load-shedding scheme that provides emergency protection against excess frequency decline, in cases when the Kosovo power system might be disconnected from the regional transmission network. The proposed load-shedding scheme uses the local frequency rate information to adapt the load-shedding pattern to suit the size and location of the occurring disturbance. The proposed scheme is tested in a software simulation on a large scale PSS/E model which represents nine power system areas of Southeast Europe including the Kosovo power system.

Keywords**—**About Load Shedding, Power System Transient, PSS/E Dynamic Simulation, Under-frequency Protection

I. INTRODUCTION

LOAD shedding as the last resort to avoid a major power system breakdown has been utilized for a long time. It is mainly triggered by under-frequency or under-voltage protection relays and actuated by distribution system circuit breakers. Proper design of load shedding schemes which include proper settings of under-frequency protection is most relevant issue to ensure smooth load relief, in situations where the power system otherwise would go unstable

A. Load shedding

Each part of the power system can be unbalanced should the load exceed the generation. In order to maintain the power balance in the system, generators accommodate by decelerating generator rotor speed. At the same time, the interconnection lines to which the system is linked tend to cover the generation deficit impacting thus in the increase of mechanical power of turbines on the generators at the neighboring systems. This combination of events can lead to the overload of interconnection lines and their tripping which can cause dangerous vibrations, or detachment of parts of system thus causing serious instability in power systems. In this case parts of generation and load systems may remain isolated from the strong power grid and as a consequence of their unbalance the loss of power system stability can occur.

The consequence of generation unbalance versus load (the case where the load exceeds the generation) is indicated with the frequency decline from the nominal value of 50Hz. The work of generators with the frequency below the critical values affects negatively the generator. Such effect in the cases of hydro-generators, even with a drop up to 10%, is not as great as in the cases of thermal generators as the latter are sensitive even for the values above 5%. The outgoing power of thermal generators depends on a range of auxiliary equipment, such as motor drives, water circulation pumps, etc. When the system frequency begins to drop then the outgoing power of the installed equipment on the power plant starts to decline rapidly affecting further reduction of the generator's power output. This range of events with cascade effect starting from the frequency decline with a direct effect on the reduction of power output causes a continuous frequency decline up to the loss of stability on the generator and loss of synchronism and consequentially by their final tripping and disconnection.

In order to avoid total decline of the system's isolated part, the under-frequency protections are applied in every power system in order to activate automatic load-shedding i.e. by switching off certain segments of the power system load aiming thus to balance generation and load [1].

B. Characteristics of the Kosovo power system

Proper realization of the under-frequency protection is necessary in order to study the Kosovo power system from the frequency-power point of view. Every power system has a different response and behavior in terms of frequency-load reaction because this dependence is extremely complex considering the influence of the range of factors, such as inertia constant of the system, interconnections with neighboring systems, characteristics of the generators and auxiliary equipment, grid configuration, type of event, etc. All these factors make the power system to be characterized with unique behavior.

Proper realization of the under-frequency protection is necessary in order to study the Kosovo power system from the frequency-power point of view. Every power system has a different response and behavior in terms of frequency-load reaction because this dependence is extremely complex considering the influence of the range of factors, such as inertia constant of the system, interconnections with

---

A.Gjukaj is with the Kosovo Energy Corporation-KEK, st."Ilaz Kodra" n.n, Pristina, Kosovo, (e-mail:arben.gjukaj@kek-energy.com)

G.Kabashi is with Kosovo Transmission System and Market Operator – KOSTT, st."Ilaz Kodra" n.n, Pristina, Kosovo (corresponding author; phone: +37744297028; e-mail: gazmend.kabashi@kostt.com)

G.Pula N.Avdiu and B.Prebreza are with Electrical and Computer Engineering Department of University of Prishtina, st."Bregu i Diellit" n.n. Pristina, Kosovo.(e-mail: gazmend.pula@gmail.com; nysretavdiu@gmail.com; bprebreza@hotmail.com).

neighboring systems, characteristics of the generators and auxiliary equipment, grid configuration, type of event, etc. All these factors make the power system to be characterized with unique behavior.

The system is to be analyzed in terms of frequency changes in the cases of load increase versus generation.

Such a change between the generated power and the load power is known as generator overload. In such cases generators will increase the mechanical power on the turbine through the primary regulation (rotation reserve, if any), so that the frequency point would be kept near to the nominal value of 50Hz. However, if the generators reach the regulation limits whereas the system remains in the island mode of work then the rapid frequency decline will occur.

In these cases if the under-frequency protections are not activated for automatic switch off of the load, the under-frequency protection (47.5Hz) of generators will carry out their tripping off avoiding possible damage on the generator system. The basic characteristic of the frequency change of the power system is provided through the swing equation:

$$\frac{H}{\pi \cdot f_0} \frac{d^2\delta}{dt^2} = P_{m(pu)} - P_{e(pu)} \tag{1}$$

This non-linear differential equation defines the frequency change depending on the difference between the electrical and mechanical powers, respectively, from the unbalance between the generation and the load [2]. In the figure 1 the system frequency dependence is shown depending on the level of generators overload.

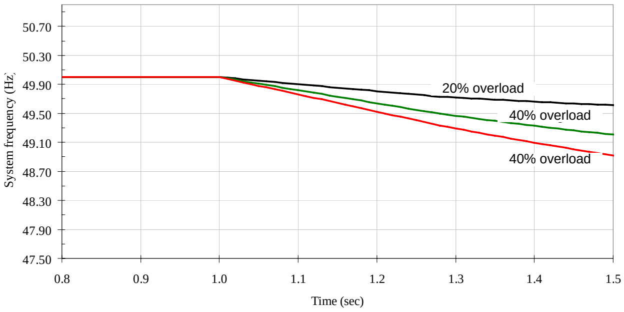

Fig.1 System frequency response from different value of generator overloading

C. Definition of the power system critical configuration

Power system in Kosovo is strongly interconnected with strong regional networks of 400 kV voltage level, whereas with the network of 220 kV it is connected via two relatively weak lines.

Influences of the eventual tripping of generation units due to frequency changes are relatively low if our systems remains interconnected with the strong regional network of 400kV. Generation unbalance upon a transitional process is offset by the interconnection so that the frequency returns fast to its normal values. In fig.2 is seen the configuration of the transmission grid 2009/2010, which is presented only for the voltage levels of 400 and 220kV [3].

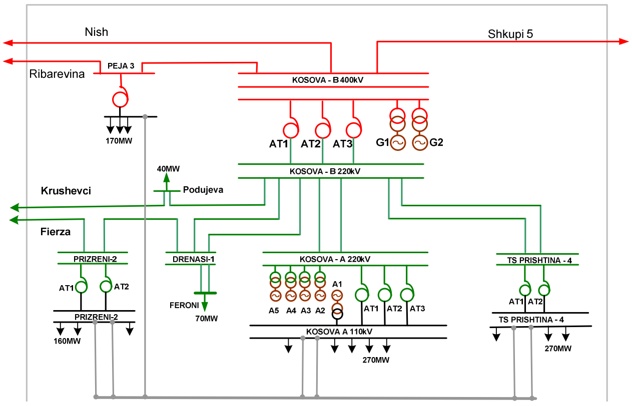

Fig. 2 Horizontal network of the Kosovo power system

However, based on the dispatch experience it can be noted that the power system faces a range of unexpected events, both of high and low probability. In order to define the program for automatic load shedding in cases of frequency decline below the allowed values, it is required to identify the critical case for such an event, which is related to the frequency drop in the largest part of the system. This occurs if a large amount of consumption remains prevailingly on an island mode of supply and as such it overloads the generators and interconnection lines of 220kV.

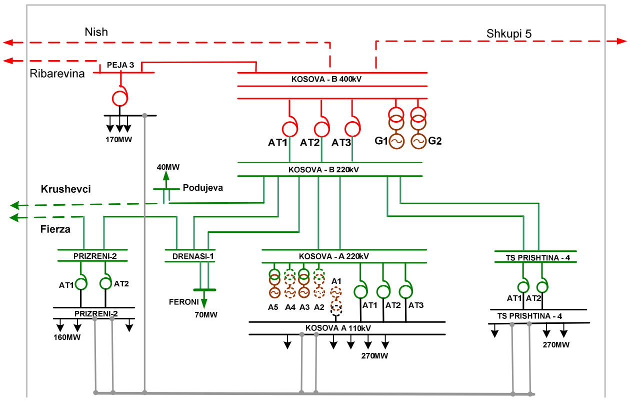

Fig.3 The case where the entire Kosovo power system operates isolated.

II. FREQUENCY -LOAD ANALYSIS OF THE KOSOVO POWER SYSTEM IN ISOLATED MODE OF OPERATION

This case represents a typical case of functioning of the Kosovo power system in an island mode of operation. The stability of generator frequencies will depend on the unbalance between the generation and the load. Prior to the development of the automatic load shedding program it is necessary to define the maximum level of generator overload, the maximum level of the load to be switched off, the level of frequency for which the automatic load shedding i.e. switch off would be initiated, the maximum value of allowed decline of frequency, as well as optimal definition of the time delay relay.

D. Maximal overload

Determination of level of overload of generators is calculated using the following formula:

$$\%(\text{overload}) = \frac{\text{load} - \text{generation}}{\text{generation}} \cdot 100 \qquad (2)$$

It is very difficult to define the level of system overload to be encountered particularly with systems having strong interconnections as our power system. Situation becomes more difficult based on the performance characteristics that the configuration of our system will bring about now or in the next two years. This applies particularly in critical cases such as sudden disconnections from the interconnection. In these events certain elements of the system are overloaded to the critical values, which depend mainly on the level of system overload at the time of occurrence. If such overload element values exceed the range of normal overload levels then the current values enters in the range of over-current protection actuation (I>>) with a time delay being shorter than the time of frequency decline in the level of under-frequency protections actuation. Therefore the analysis is focused in cases where system is entirely isolated from the interconnection [4-5].

System is analyzed with 55% overload of the thermal power plant generators i.e. TPP Kosova B+TPP Kosova A plus to include hydro plant HPP Ujmani for different cases of generator load levels as given in the table below:

III. DYNAMIC SIMULATION WITH PSS/E

The study is carried out on a large scale PSS/E model having over 9 interconnected areas representing given countries of Southeast Europe power systems including the Kosovo Power System. Kosovo power system is modeled in detail while the rest of the regional interconnections only as horizontal networks (400kV and 220kV).

TABLE I
GENERATOR OVERLOAD FOR DIFFERENT GENARATION AND DEMAND RATIO

System generators after event [MW]	Bruto Consum. [MW]	Over-load [%]
1x250MW+1x110MW+32MW= 392MW	607.6	55
1x250MW+2x110MW+32MW= 502MW	778.1	55
2x250MW+1x110MW+32MW= 642MW	995.1	55
2x250MW+2x110MW+32MW= 752MW	1165.6	55

The model consist of three types of simulation data files: power flow data file, dynamic model data file and sequence model data file. Initial dynamic model data file for the regional power system is used for the study case. The dynamic data file so called dyn.file in PSS/E consist of dynamic parameter data for all conventional synchronous generators, turbines, exciters governors and other devices. The first step in dynamic simulation using initial dynamic file is to enter the sequence data of occurrence to evaluate load shedding impact on frequency restoration, which is saved in a file [6].

The system behavior was analyzed for dynamic processes according to the first case where our system operates fully in an island mode of operation. This model includes all projects of transmission and distribution network reinforcements that are expected to be completed by the year 2011.

In this model the simultaneous opening of interconnection lines was simulated with the generator units under operation affected by an overload of 55%. The focus of monitoring is the system frequency in order to define the optimal program for automatic load shedding/tripping. Disconnection i.e. tripping time of protection relays is taken to be 100ms

E. Analysis of optimal actuation of under-frequency protections

In order to define the program for automatic tripping, subject of analysis was also the isolated operation mode of the power system from the interconnection with different scenarios of domestic generation capacities. The system frequencies in the operation mode of full isolation from the interconnection for four different cases of generation are given in page 4 on the basis of the table 1.

Normally the steps and load shedding/tripping time and the setting of time delays are key factors related to the characteristic of the power system. For the Kosovo power system the load /shedding tripping in four stages i.e. in four steps is optimal as dynamic impacts in the system would be lower.

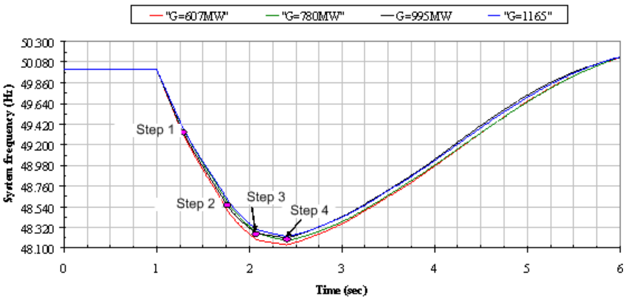

Fig.4 Dependency of frequency decline from the system generated power.

From the figure 5 it can be seen that the speed i.e. gradient of frequency change df/dt [Hz/s] for a constant load will be in an equal ratio with generation capacities available at the time of system isolation. For the load of 55% of generators, in the island mode of operation, the maximal speed of frequency decline of the Kosovo power system after the activation of its under-frequency protections is -2.5Hz/s for the generation of 607 MW.

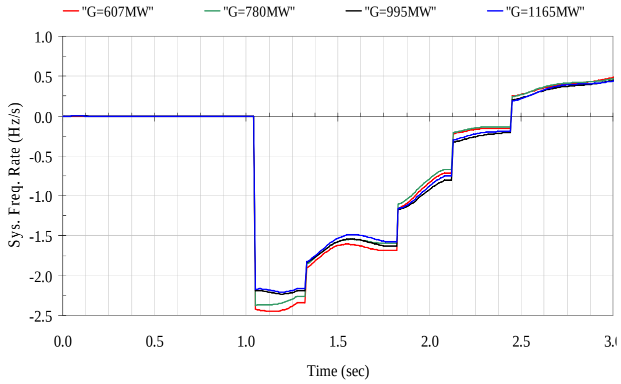

Fig.5 Dependency of frequency decline speed from the system generated power and load shedding steps.

The nature of the system frequency change was analyzed in terms of the system generator overload. Fig. 6 presents three cases of frequency dependency from the generator overload of 20%, 40% and 55%.

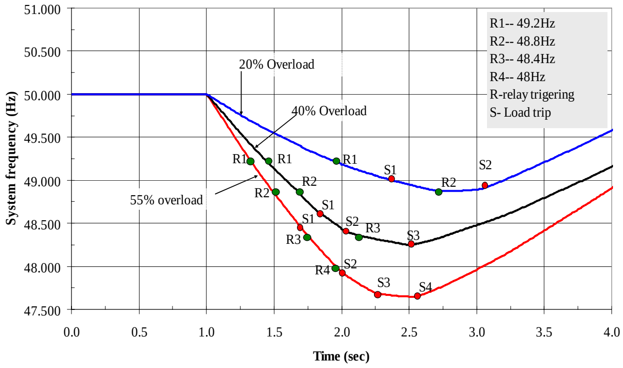

Fig. 6 Characteristic of system frequency-time for parameter-setting of under-frequency relays

As advanced technology of protection relays has been applied to under-frequency relays their features include high actuation accuracy. Depending on the power system size, its interconnection with other systems, system inertia and its configurations, two actuation methods can be applied to under-frequency protection as applied to automatic load shedding/tripping. These methods differ in the nature of the signal that the relay uses for tripping initiation. These two methods are conventional and adaptive methods [ ].

Conventional method uses the system frequency **f** as the main relay input signal. The relay actuation is based upon the frequency value. Usually the load tripping is done in the steps from 3 to 5 and with a time delay of 0.2-0.6sec from the relay initiation time to the signal delivery for switch off. Parameters of frequency threshold are determined in full accordance with the Distribution Code, whereas time delays are defined from dynamic simulations in order to avoid unnecessary load shedding. This method is usually applied to smaller power systems..

Adaptive method uses the frequency speed decline df/dt as the main relay input signal. This method is placed to the systems facing unbalance due to different system occurrences or faults which result with greater frequency speed decline. In this method the minimal frequencies will be higher than in the conventional method. The adaptive method is mainly applied to power systems that import greater amounts of power via interconnection lines.

Conventional method is the most suitable method for the Kosovo power system until the period when our system will have achieved a greater increase of generation capacities. When this stage is reached the method which is used in under-frequency protection for the automatic load shedding shall be changed. Similarly, the system dynamic simulations indicate that the conventional method meets the criteria required for under frequency protection always in accordance with distribution code.

F. Definition of under-frequency relay optimal actuation for the Kosovo power system

Generator overload in the maximal value of 55% has been taken as the most critical case that can appear in the Kosovo power system. Based on findings yielded from the dynamic complex simulations the optimal actuation scheme of under-frequency protection has been defined [7-8]. Basic parameters of the relay parameter setting to be placed on the distribution feeders of the 110/35 kV and 110/10kV Substations will be as in the table below:

TABLE II
GENERATOR OVERLOAD FOR DIFFERENT GENARATION AND DEMAND RATIO

Under frequency protection	Step I	Step II	Step III	Step IV
% of load shedding	10	15	15	15
Relay time delay (seconds)	0.3	0.4	0.3	0.3
Relay initial frequency	49.2	48.8	48.4	48.0

Following aspects must be taken into account during the activation process of the under-frequency protection for automatic shedding i.e. switch off:

- Determination of distribution feeders 35kV and 10kV with high supply priority and those with power priority shall be under the responsibility of KEK - Distribution.
- Relay parameter setting, their installation and testing shall be done with joint expert teams for protection from KOSTT and KEK.
- Programming scheme of the under-frequency protection activation shall be revised on yearly basis under consideration of continuous changes of the characteristics of the Kosovo power system.
- Relays to be installed shall be modern-numeric, which are characterized with high accuracy and not sensitive to the voltage level.
- Programming schemes of the under-frequency protection activation cannot be changed from the parties connected to the transmission grid.

IV. CONCLUSION

Power flow and dynamic analysis were made in order to check the influence of island mode of operation of the Kosovo power system and to ensure proper load shedding scheme. The large scale PSS/E model was used for computer simulation. This paper focuses on the complex interactions between load and generation in power systems. Knowledge about this interaction is crucial to develop load shedding schemes which better reflect consumer and societal power supply requirements than most existing schemes. Power system stability requires high-speed load shedding. These distinct requirements can be addressed separately using technology that best fits each purpose.

ACKNOWLEDGMENT

This work has been supported by Kosovo Energy Corporation - KEK and Kosovo Transmission System and Market Operator – KOSTT.

REFERENCES

[1] Protective Relaying-Principle and Application,third Edition, J.Lewis Blackburn, Thomas J.Domin CRC Press, New York, ISBN 1-57444-716-5, pp.541-638

[2] ”Power System Control and Stability” Second Edition, P.M.Anderson, A.A. Fouad, , WILEY-INTERSCIENCE , ISBN 0-471-23862-7, pp.13-48

[3] Transmissions Network Development Plan (2010-2019) www.kostt.com

[4] Under voltage Load Shedding Guidelines**,** Western Electricity Coordinating Council, July 1999.

[5] System Protection Schemes in Power Networks, CIGRE Technical Report no. 187, June 2001

[6] PSS/E manual, version 32

[7] Grid Cod KOSTT, www.kostt.com

[8] Distribution Code www.kek-energy.com

Arben Gjukaj holds an undergraduate degree in Electrical Engineering from Polytechnic University of Tirana, a Masters Degree of Science in Service Management as well Ph.D applicant at the Polytechnic University of Tirana.He is the CEO of KEK (Kosovo Energy Corporation), a position he has held since June 2008. During his 10 years at KEK, he held other responsible positions including Acting Managing Director, Executive Director of the Network Division, Head of a Sector in Commercial Division, and conducted power generation planning studies.

Gazmend Kabashi received his electrical engineering ing. Degree from University of Prishtina, Kosovo in 2003, the M.S. degree from the University of Prishtina in 2008. He is a Ph.D. applicant at the Electrical Power Systems of the University of Prishtina. Since 2003 he is with Transmission System and Market Operator of Kosovo (KOSTT) working on long term development of transmission network. His research interests are in transient stability of power systems and Wind Energy Integration in Power System.

Gazmend Pula obtained his electrical engineering B.Sc. degree from the University of Prishtina, Kosovo in 1977, the M.Sc. degree from the George Washington University in Washington DC, USA in 1981, whilst the Ph.D. degree from the University of Prishtina in 1995, all in the area of electrical power systems. Currently he works as professor at the Faculty of Electrical and Computer Engineering of University of Prishtina. His research interests are in power system control with focus on power system transient stability.

Nysret Avdiu obtained his electrical engineering B.Sc. degree from the University of Prishtina, Kosovo in 1976, the M.Sc. degree from the University of Zagreb 1983, Croatia and whilst the Ph.D. degree from the University of Prishtina in 1993, all in the area of Electrical Power Engineering. Currently he works as professor at the Faculty of Electrical and Computer Engineering of University of Prishtina. His research interests are in Power Electrical Engineering and Regulation.

Bahri Prebreza received his electrical engineering Degree from University of Prishtina, Kosovo in 1994, in vector methods for analyzing the transient processes in asynchronous motors, and Mr. sc. Degree from the University of Prishtina in 2007, in switched reluctance motors and their control. He is Pd.D. applicant at the Electrical Power Systems in the University of Prishtina. Since 2008 he is working on the outages of the electro energetic systems caused from atmospheric discharges. His research interests are electrical machinery, power electronics, automatic regulation and high voltage engineering.