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The Automatic Load Shedding for Stability Security at the Load Buses

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Abstract: This paper proposes a new algorithm for the automatic under voltage load shedding operation of the radial grid to secure the static stability over the bus voltage change in a complex power system. The algorithm is developed on the basis of voltage stability index, comprising, explicitly, grid's operational parameters and accounting for the regulating effects of reactive and active power components over voltage change.

Key Words: Load Shedding, Voltage Stability, Reactive Power

Introduction

It is now more important than ever to design and operate power systems with not only the highest practicable efficiency but also the highest degree of security and reliability (Miller, 1982). A voltage collapse of part of the electrical system is an indication that in the existing conditions and contingencies, some portion of the combined generation and transmission system has been operated beyond its capability. When the system starts to collapse, there is a real danger that the localized problem will cascade into wider area, and the action must come to contain the impacts of disturbances to localized areas to protect the system from voltage collapse, or uncontrolled loss of load (Guidelines, 1999).

The high-speed automatic Under Voltage Load Shedding (UVLS--under voltage automatic load shedding) has found a wide application in securing electric power stability and bringing back the voltage to minimum operating voltage level or higher. This method of securing stability is particularly effective if the receiving part has an accumulated energy consumer, the cutting-out of which does not inflict considerable damage.

While designing UVLS schemes, important points should be taken into consideration such as the coordination with protective devices, time delay for load dropping initiation, consumer priority of tripping, ...etc.

The input signal into automatic UVLS unit with respect to load stability security is formed by voltage decrease to a value V_c due to any additional factor (for example the cut-out of one of the parallel transmission lines). Determination of V_c is tied with great difficulties, caused by the necessity of the adequate knowledge of static (or dynamic) load characteristics over voltage change, which influence the analysis and calculation of amount of load needed to be shed to stabilize the system voltage (IEEE,1998), whereas these characteristics may vary accordingly with the change of load operating conditions.

Adjusting the automatic load shedding settings on the voltage V_c is considered to be fixed and non-adaptive to real existing conditions, so the redundancy of power cutout is likely to occur. Therefore, it is expedient to develop special automatic load shedding operation algorithms that should possess, at least, partial adaptation to power system varying conditions. The application of these algorithms is stimulated by several factors, such as the expanding of the microprocessor applications in power systems, which allow to perform highly complicated automatic operations, the growing of info-power systems, supplied by telecommunication and telemetring devices, computers, etc (Jan *et al* ., 1997).

Fig. 1: Single Line and Phasor Representation for a Load Connected to Radial Grid System

The Practical Criterion of Stability Assessment over Radial Grid Voltage Changes: Consider the radial grid system, in which the load is connected to a system S by a single feeder (Fig. 1).

The system voltage stability is affected by both **P** and **Q** and at each operating point, **P** may be kept constant And the voltage stability can be evaluated by considering the incremental relationship between **Q** and **V** (the effects of change in system load are taken into account by studying the incremental relationship between **Q** and **V** at different operating conditions) . (IEEE, 1990).

For this grid ,the Jacobian matrix equation can be developed connecting the unbalanced active and reactive power components at a load bus with the incremental change in bus voltage angle and its magnitude (Kundur,1994).

$$\begin{bmatrix} \Delta P_{un} \\ \hline \Delta Q_{un} \end{bmatrix} = \left[\begin{array}{c|c} \dfrac{\partial P_{iL}}{\partial\theta} & \dfrac{\partial P_{iL}}{\partial V} - \dfrac{\partial P_{L}}{\partial V} \\ \hline \dfrac{\partial Q_{iL}}{\partial\theta} & \dfrac{\partial Q_{iL}}{\partial V} - \dfrac{\partial Q_{L}}{\partial V} \end{array}\right] \cdot \begin{bmatrix} \Delta \theta \\ \hline \Delta V \end{bmatrix} \tag{1}$$

Where:

ΔPun -incremental change in the unbalanced active power of the load;

ΔQun -incremental change in the unbalanced reactive power of the load;

Δθ- incremental change in bus voltage angle;

Δ V- incremental change in the bus voltage magnitude

The elements of the Jacopian matrix give the sensitivity between power flow and bus voltage changes.

If ΔP_{un} is not taken into account (assuming $\Delta P_{un} = 0$), then:

$$\Delta Q_{un} = \frac{\dfrac{\partial P_{iL}}{\partial\theta}\left(\dfrac{\partial Q_{iL}}{\partial V} - \dfrac{\partial Q_{L}}{\partial V}\right) - \dfrac{\partial Q_{iL}}{\partial\theta}\left(\dfrac{\partial P_{iL}}{\partial V} - \dfrac{\partial P_{L}}{\partial V}\right)}{\dfrac{\partial P_{iL}}{\partial\theta}} \cdot \Delta V \tag{2}$$

Neglecting line resistance, the elements of the Jacobian matrix can be determined as follows:

$$\frac{\partial P_{iL}}{\partial\theta} = V_i V_j b \cos\theta$$

$$\frac{\partial Q_{iL}}{\partial\theta} = V_i V_j b \sin\theta$$

$$\frac{\partial P_{iL}}{\partial V_i} = V_j b \sin\theta$$

$$\frac{\partial Q_{iL}}{\partial V_i} = 2V_i b - V_j b \cos\theta$$

$\dfrac{\partial P_L}{\partial V} = K_{PV}$, $\dfrac{\partial Q_L}{\partial V} = K_{QV}$, -The regulating effects of load's active and reactive power components, respectively.

The load stability criterion over voltage Kundur (1994) is conditioned as:

$$\frac{dQ_{nb}}{dV} \approx \frac{\Delta Q_{nb}}{\Delta V} < 0 \tag{3}$$

If the above-mentioned quantities of partial derivatives are substituted into (2), then stability criterion will take the following form:

$$\begin{aligned} \frac{dQ_{un}}{dV} &= -2V_i b + V_j b\cos\theta - K_{QV} - \frac{-\sin\theta(-V_j b\sin\theta - K_{PV})}{-\cos\theta} = \\ &= -2V_i b - K_{QV} + \frac{V_j b(\cos^2\theta + \sin^2\theta) + K_{PV}\sin\theta}{\cos\theta} = \\ &= -2V_i b + 2V_j b\frac{1}{\cos\theta} - K_{QV} + K_{PV}\,\mathrm{tg}\theta < 0 \end{aligned} \tag{4}$$

The Structure of the Automatic UVLS Operation: On the basis of criterion (4), the algorithm of the automatic load shedding operation has been developed (Fig. 2).

The following data are the input information's: -

Vj:-the voltage of the power system's node, from which load is being fed;

Vi- the voltage of the load node, at which stability is to be controlled;

P_i, Q_i -active and reactive powers, being supplied to the load node;

b-grid susceptance between nodes *i* and *j*;

S_{1F}, ... S_{nF},- total power for each outgoing load fee

From the input information's, the phase angle θ between nodes *j* and *i* may be determined using the following formula:

$$\theta = \mathrm{arctg}\,\frac{\dfrac{P_i}{bV_i}}{V_i + \dfrac{Q_i}{bV_i}} \tag{5}$$

The determination of the regulating effects for the active and the reactive components of power may be achieved by three ways:

1. If there is no information about the load characteristics, then the regulating effects may have the following values $K_{PV} = 0.9 \pm 0.5$, $K_{QV} = 3.9 \pm 1.8$, they are considered to be very roughly values.
2. If only the statical characteristics are known, then the regulating effects of the load at a constant frequency can be found from the following equations (Gubina and Strmcnic, 1995):

$$\begin{aligned} \frac{\partial P_L}{\partial V} &= K_{PV} \\ &= ap + 2bp \\ \frac{\partial Q_L}{\partial V} &= K_{QV} \\ &= aQ + 2bQ \end{aligned} \tag{6}$$

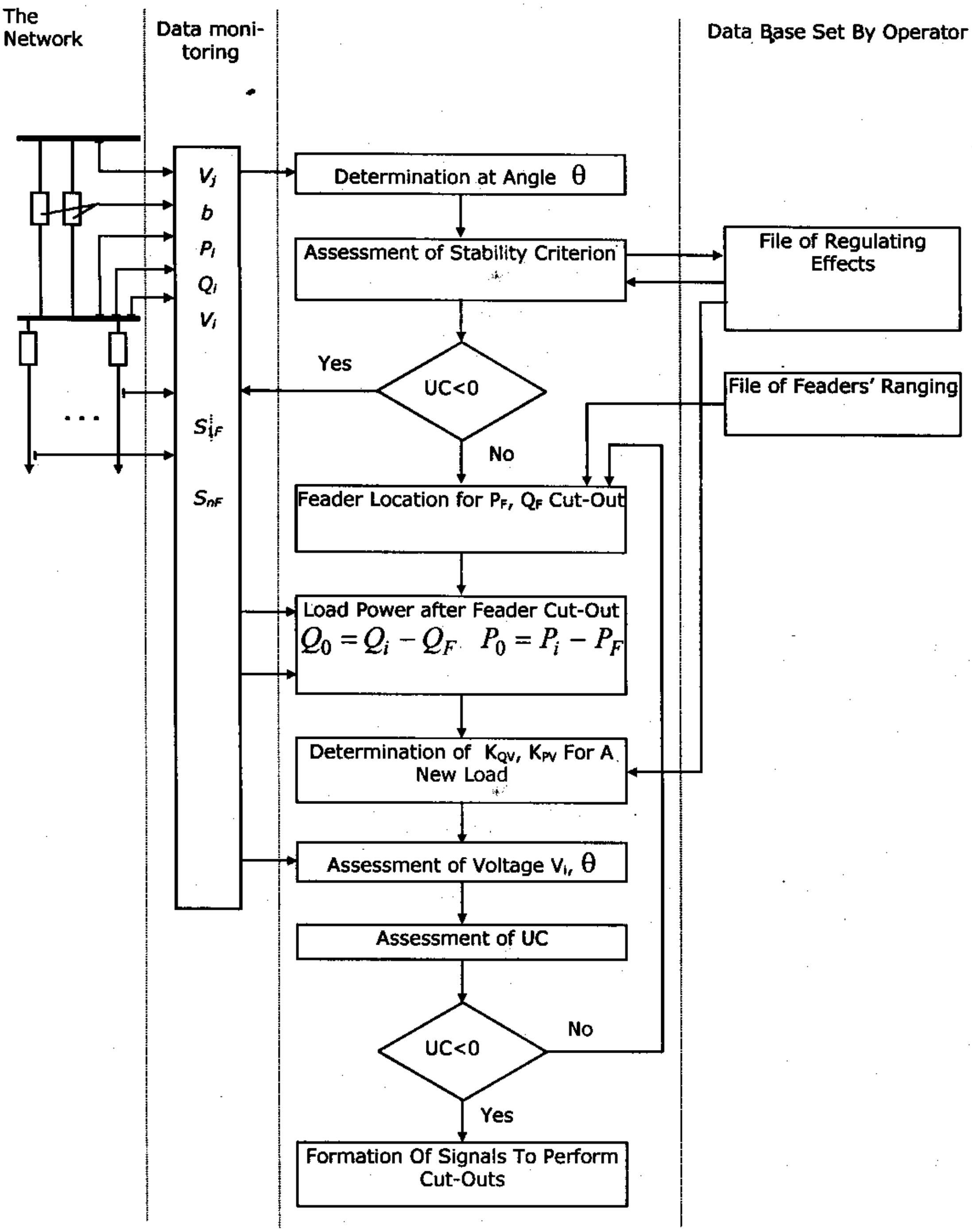

Fig. 2: The Automatic Load Shedding Algorithm

3. If the load is represented as equivalent to an induction and synchronous motors and a static load, the system of which is described by equations presented in the form of state variables of the form:

$$\frac{dx}{dt} = Ax + BU \tag{7}$$

$$Y = Cx + DU;$$

Where, the output coordinate *Y* determines the reactive power, while the input coordinate is the voltage. In the Steady state mode of operation, the operator $\frac{dx}{dt}=0$. The regulating effect (K_{QV}) can be found from the relation:

$$K_{QV} = \frac{Y}{V} = \frac{\Delta Q}{\Delta V} = D - CA^{-1}B \tag{8}$$

If a load bus is fed from several lines and a cut-out of one or more lines occurs, then the correction of grid susceptance must be done, which is determined in normal operating conditions from the parallel connection of lines. When a line is being cutout, the new value of susceptance for the feeding grid becomes:

$$b'_e = b_e - b_l$$

Where b_e - grid susceptance in normal operation;
b_l - susceptance of the cut-out line.

On the basis of the determined values of the power regulating effects over voltage and the data obtained from monitoring system, it is possible to evaluate load stability criterion over voltage in real time (Gubina and Strmcnic, 1995):
If (the stability index) *UC* <0, the load is stable over voltage.
If *UC* >0, the load is statically unstable over voltage.
In case if *UC* >0, the load is statically unstable, a question will rise about minimal quantity of load capacity which is to be shed in order to secure the load bus stability. In this aspect, we ought to consider the necessity of arranging consumers' tripping succession depending on their responsibility degree, which may be carried out by assigning to every consumer a responsibility degree, i.e.$F_1 \ldots F_n$.
With *UC*>0, the least responsible feeders are being selected and the capacities of these feeders, proceeding from monitoring system. Then the remaining load capacity is calculated after the selection of the cut-outs of load connections:

$$Q_0 = Q_i - Q_F, P_0 = P_i - P_F.$$

It should be noted, that Q_i P_i - are load capacities, genuinely consumed at the given time instant.
The obtained information permits to assess voltage at a load node, if a series of connected lines are being cutout. Having this in mind, we make use of the well-known relation:

$$V_j = \sqrt{\left(V_i + \frac{Q_0 x}{V_i}\right)^2 + \left(\frac{P_0 x}{V_i}\right)^2}$$

$$V_j^2 = \left(\frac{V_i^2 + Q_0 x}{V_i}\right)^2 + \left(\frac{P_0 x}{V_i}\right)^2$$

From which the following equation will be obtained:

$$V_i^4 + \left[2Q_0 x - V_j^2\right]\cdot V_i^2 + \left[(Q_0 x)^2 + (P_0 x)^2\right] = 0.$$

The solution of this equation gives:

$$V_i = \sqrt{-\frac{2Q_0 x - V_j^2}{2} + \sqrt{\left(\frac{2Q_0 x - V_j^2}{2}\right)^2 - \left[(Q_0 x)^2 + (P_0 x)^2\right]}}.$$

After the determination the voltage V_i , it becomes possible to find the angle θ from (5). Then, using (4), stability criterion under a given quantity of cutout capacity can be determined. If stability cannot be secured, the number of cutout connections must be increased. Iterative process continues unless minimal connection number is established, that have to be cutout in order to secure stability.

Conclusion

The proposed algorithm of automatic Under Voltage Load Shedding to reserve stability has been developed on the basis of the load stability criterion and it has the following properties:

1. The algorithm has an adaptive character toward various electric power system operating conditions and it is worked out to select minimal out-going feeders from the load.
2. This algorithm is worked out at radial grid; in which voltage at the beginning of the line may be considered independent on power system operation.

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