

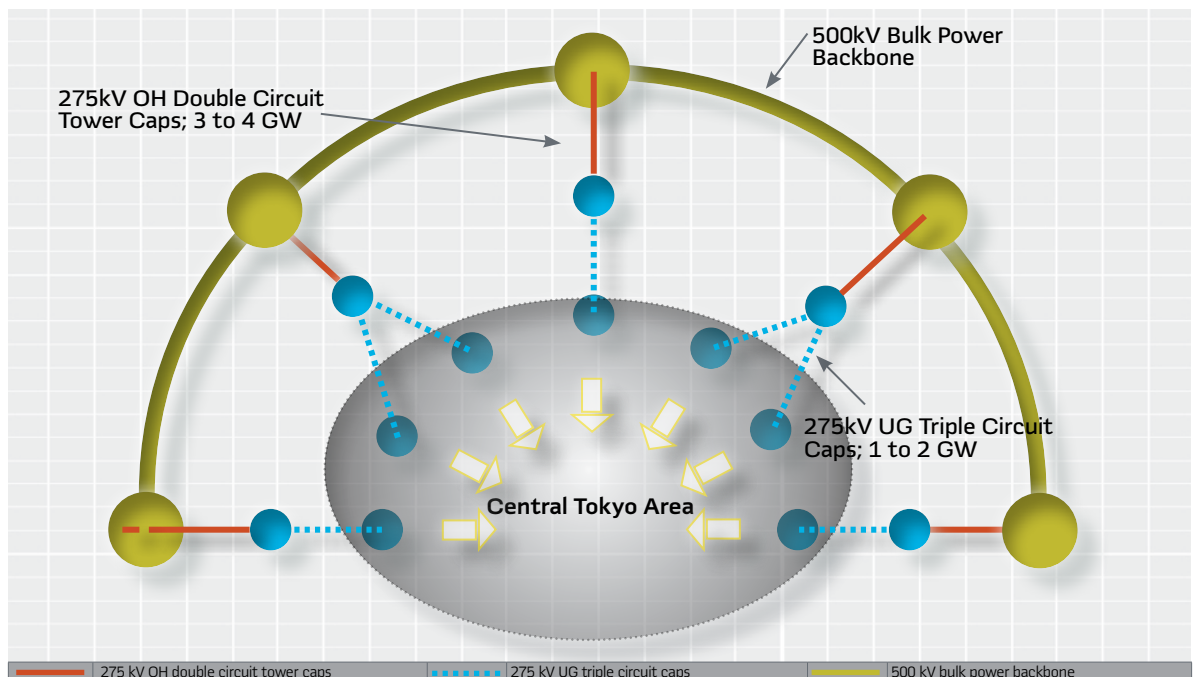
Islanding Protection with Active and Reactive Power Control

The Metropolitan power system owned and operated by Tokyo Electric Power Company consists of several radial sub-power systems. Each sub-power system receives electric power from the 500 kV mesh bulk power system, via 275 kV parallel overhead transmission lines and three 275 kV underground cable circuits which take the same route. These sub-power

systems cannot be interconnected to one another due to the restrictions imposed by short-circuit fault current. **One of these metropolitan power systems supplies many politically and economically important loads and the load capacity of the locally installed power plant is small.**

1 Bulk power system configuration in central Tokyo area

The central area of Tokyo is supplied from a 500 kV bulk power system.





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An Islanding Protection System is installed to protect important customers in case of power failure.

the system may collapse as a result of generator under frequency tripping unless high speed load shedding is initiated.

However, the integrity of the separated system cannot be assured solely by load shedding. If many loads are shed for active power balance control, the reactive (inductive) power of the loads and reactive power loss of the transformers will also be lost, so a system possessing a large shunt capacitance will suffer from the effects of serious overvoltage caused by severe reactive power

Power System and Actual Operational Experiences

Most of the indigenous load is supplied from the bulk 500 kV-power system via the parallel 275 kV tie transmission lines. This metropolitan system consists entirely of 275 kV, 154 kV and 66 kV underground cables. If the power supply from the bulk 500 kV- power system is interrupted by a fault on the tie transmission line, the metropolitan power system will be separated as a heavily overload system with large shunt capacitance.

We have therefore installed an Islanding Protection System with active and reactive power balance control functionality in order to protect the most important loads in the metropolitan area from serious blackouts.

On 22 November in 1999, the power system in area (1) in Figure 2 was separated from the main power system by an accident involving the 275 kV overhead tie transmission

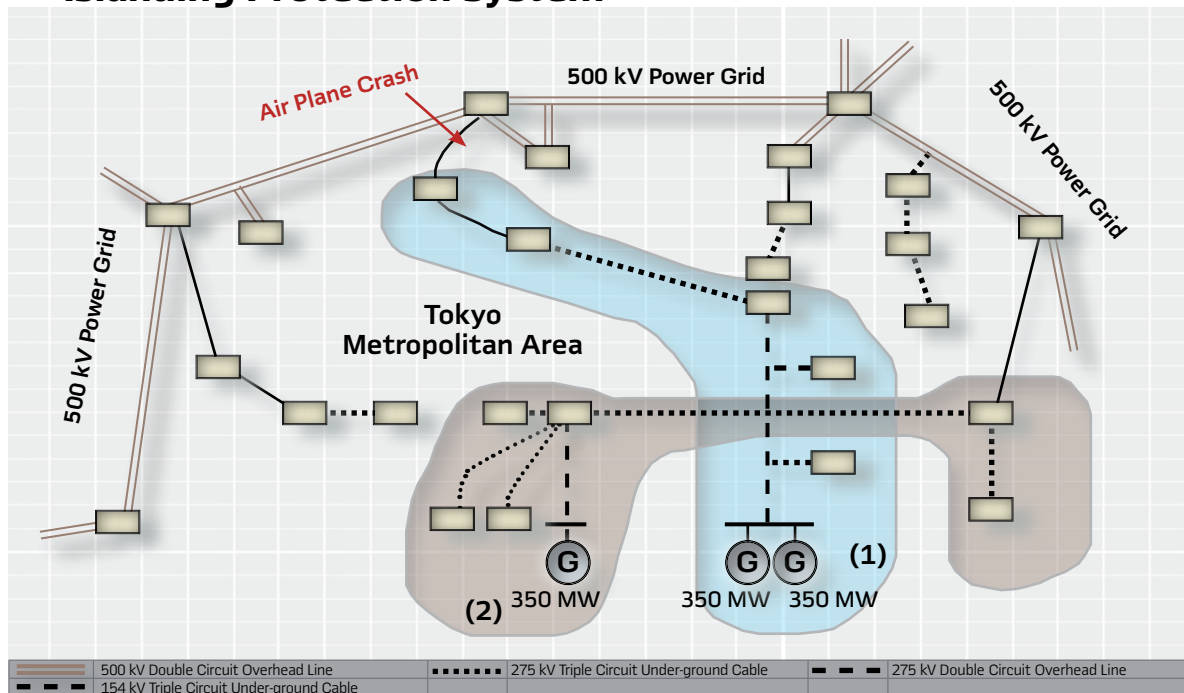
line. An Air Self-Defense Force jet training plane severed the tie transmission lines. During the course of this incident, the successful operation of the Islanding Protection System ensured that the most important customers in the metropolitan area were not affected by the power failure.

Metropolitan Power System Features

Figure 4 provides detail of the power system in (1). The peak demand is approximately 3600 MW in summer and the local power system generating capacity is 700 MW.

The total charging capacity of the 275 kV, 154 kV and 66 kV underground cables is 700 MVar. If the metropolitan power system is separated from the bulk 500 kV power system, a voltage drop will be experienced and the frequency will also drop rapidly due to severe excessive overload. As the shortage of generating capacity is very large,

2 Tokyo Metropolitan Power System and Protected Area of Islanding Protection System





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Load-shedding alone can not stabilize the separated power system.

unbalance. Therefore, it will not be possible to recover the system frequency because the power consumption will not be reduced as a consequence of the overvoltage. [load voltage characteristics such as $P = P_0 (V/V_0)^2$] Finally, the power system may collapse.

Protection System Protection Scheme

As described in the preceding section, the load shedding scheme alone cannot stabilize the separated power system. It is therefore necessary to intentionally island suitable areas where the appropriate balance of active power exists and controls the reactive power as well as initiate load shedding. The overvoltage is caused by the fact that the reactive power distribution in the separated

system is much different from that in its normal state before isolation. Hence, the most effective approach is to utilize voltage stabilization to recover the reactive power distribution in the separated system, especially at the place that will have greatest affect on the voltage and return it to the normal state prior to the separation. Figure 3 shows the concept of the stabilizing protection described above.

Protection Algorithm

The protection algorithms for the control of active and reactive power are described as follows.

■ **Active power balance calculation algorithm:** The combinations of 66 kV load feeders least matching the power received at the intentional island interconnection point are selected out of around twenty feeders. Each load feeder is ranked as A, B and C according to its importance. Particular attention is given to the politically and economically important load feeders ranked as C which are not normally selected and disconnected.

■ **Reactive power balance calculation algorithm:** The calculation of reactive power balance uses a

simplified system model. The model is simplified as shown in Figure 4 according to the following conditions:

■ As the system consists entirely of 275 kV, 154 kV and 66 kV underground cables, the series impedance of the cables can be ignored

■ The short circuit impedance of the power transformers installed at substations and power stations is taken into consideration because these series reactances affect the system voltage due to reactive power unbalance

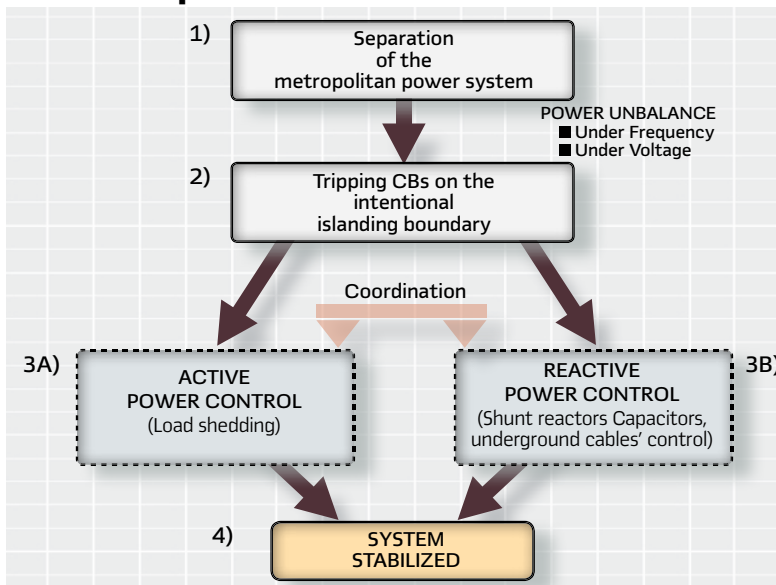
As is clear from the simplified model shown in Figure 6, the system voltage after separation is affected considerably by the reactive power flowing through the short circuit impedance of the step-up transformer (X1) in the local power station. Therefore, the reactive power control quantities such as shunt reactors insertion and underground cable tripping are calculated so that the reactive power flowing through point before and after separation should become almost equal.

Detection of System Separation

System separation is detected by comparing the node voltages between the substations in the metropolitan power system and the substations in the bulk main power system. A separation in the metropolitan power system is identified when an increase in the phase difference of the node voltages is detected as a consequence of the frequency difference caused by the system separation. If we use the auxiliary switch condition of the circuit breakers on the tie transmission lines to identify metropolitan power system separation, mal-operation (an error in identification) may occur due to some failure of

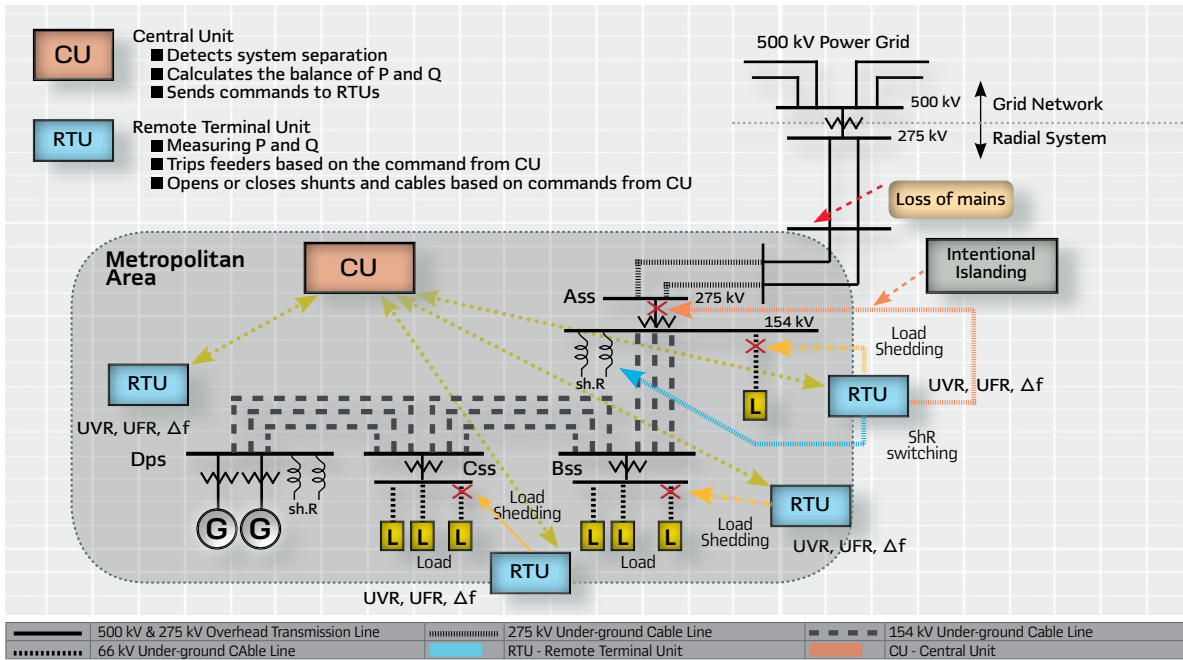
Increase in phase difference is the criteria for separation.

3 Concept of Protection Scheme

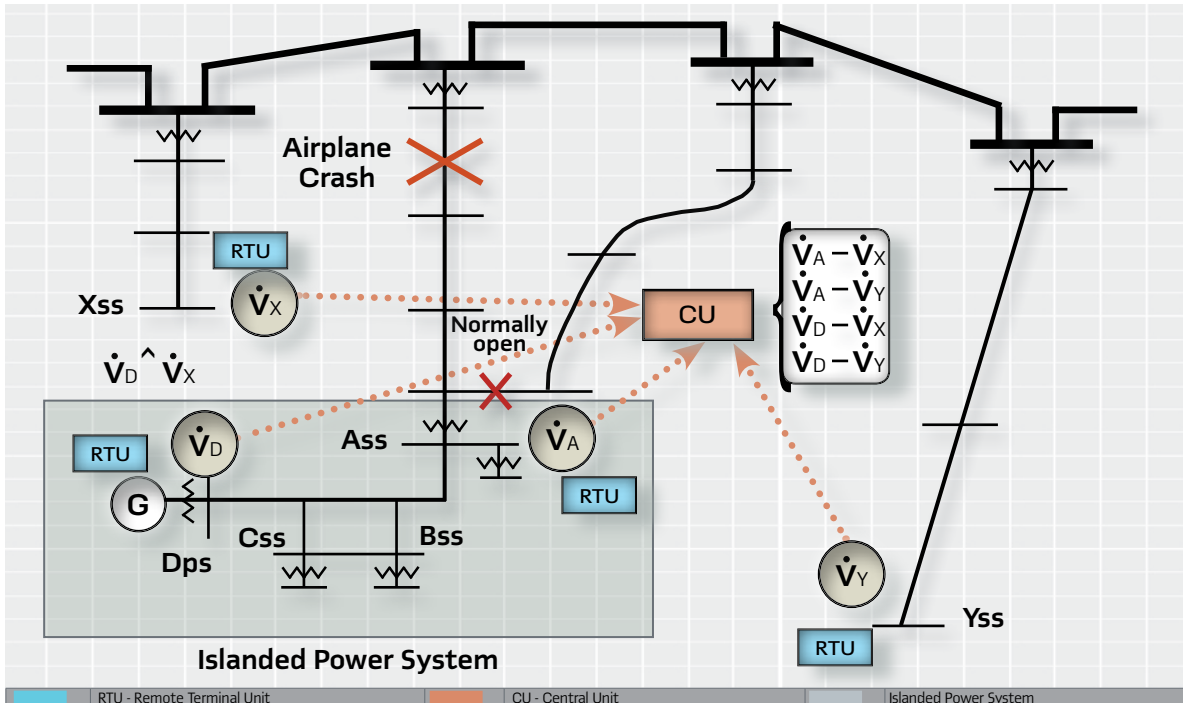


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4 Islanding Protection System - Power System and Configuration

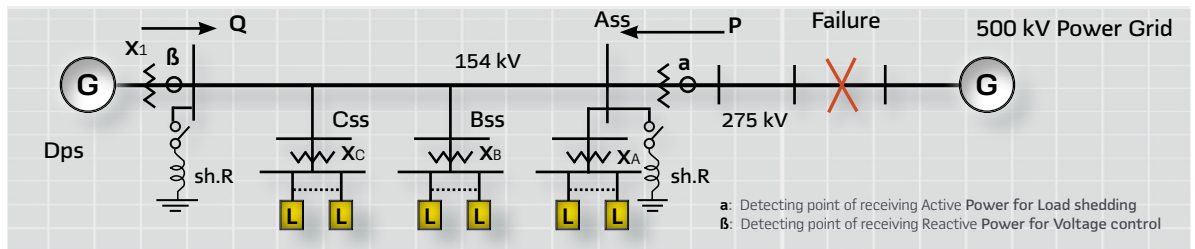


5 Frequency and Voltage of the islanded system recovered in a few seconds



Three-phase voltages at four substations are individually compared to achieve detection of system separation.

6 Simplified Power System Model for Calculation



the circuit breaker auxiliary switches or during inspection of the circuit breaker itself. The new identification method applied to our system removes these problems. As shown in Figure 5, three-phase voltages (phase-to-phase voltage) at four substations are individually compared. Power system separation is identified when the phase differences of all voltages exceed the established criterion (110°).

The microprocessor in the CU calculates the optimum control quantity using the information sent from the RTUs within 2 seconds, and the results are sent to each RTU to select the optimum

load shedding feeders and reactors etc in advance. When a power system separation is detected, the CU initiates a trip to the circuit breaker at the intentional islanding boundary and sends control commands for the RTUs. The protection control including load shedding is completed within 0.5 sec. from system separation. Figure 4 shows the overall protection system configuration and Figure 7 illustrates the control function of the system.

Actual Operational Experience

November 1999 Incident

On 22 November 1999, an Air Self Defense Force jet training

plane crashed and severed a 275 kV overhead tie transmission line which was supplying power to the Tokyo Metropolitan area. The power system, in which a thermal power plant generating around 400 MW of a total load of about 2000 MW was separated from the bulk main power system experienced a significant unbalance between generation and load.

The frequency of the separated power system dropped at a rate of 5.2 Hz/sec due to the severe unbalance between supply and demand, reaching 47.6 Hz at 0.5 sec. after the separation. The Islanding Protection System detected that the phase difference between the voltages at the bulk main power system and the system in (1) Figure 2 exceeded the set 110, and identified the power system separation. The Islanding Protection System then simultaneously performed the following actions.

Action taken by the Islanding Protection System:

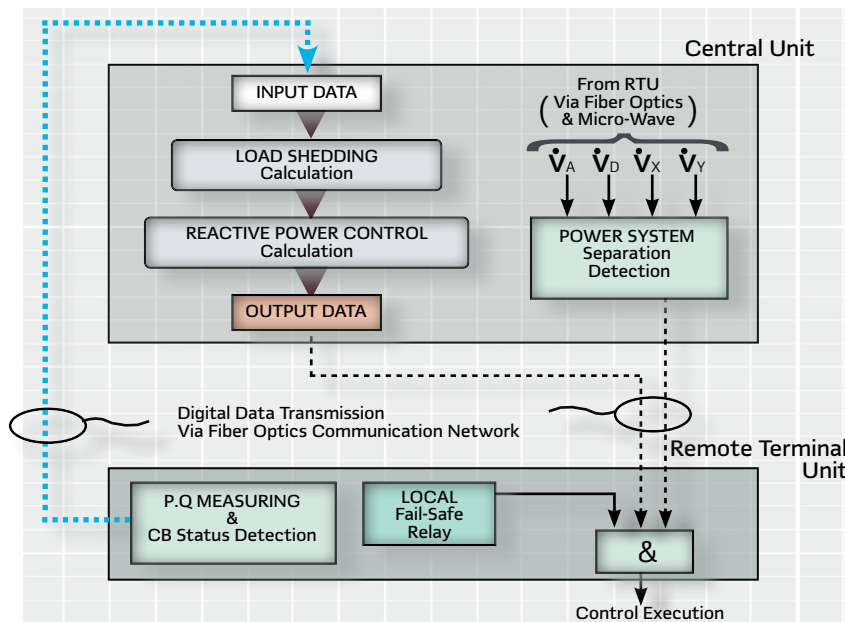
- Intentional islanding for an appropriate power system configuration containing the most important loads

- Optimum load shedding in the islanding system (100 MW, P balance control)

- Insertion of shunt reactors in the islanding system (80 MVar, Q balance control)

In the separated system, a smaller sized power system, having the most important loads with an appropriate balance of supply and demand was islanded intentionally. At the same time, optimum P and

7 Control Function



A Central Unit determines the required control action based on data from Remote Terminal Units in substations.

Q balance control was performed and then frequency recovery of the islanded system was achieved. Following this, stable operation was maintained and the system was connected with the neighboring 275 kV sub-power system about 15 minutes later.

Computation Analysis

Dynamic simulation was conducted in order to verify the events from the occurrence of system separation to immediately after the operation of the Islanding Protection System. The results are shown in Figures 8 and 9. The voltage characteristics of the loads were assumed to be as follows in this simulation.

Voltage Characteristics of load model:

$$P = P_0 (V/V_0)^2$$

$$Q = Q_0 (V/V_0)$$

Event recorders installed in a substation in the separated system

recorded the actual data shown in Figures 8 and 9.

The actual recorded data corroborates the results obtained by simulation. Subsequently another simulation was undertaken for a case in which a load of 1300 MW, equivalent to about 65% of the total load in the separated system, is shed by UFLS (*Under Frequency Load Shedding*), using the same model.

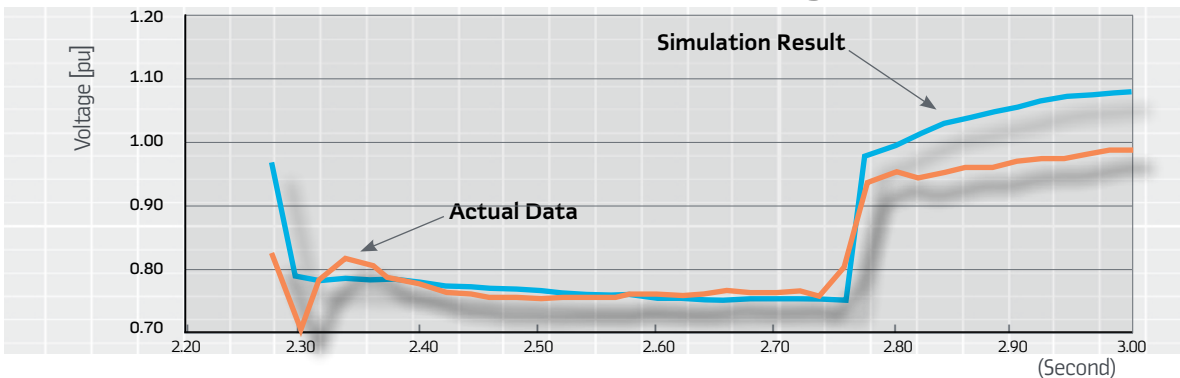
Under these circumstances it was confirmed that the frequency could not be recovered by load shedding alone as the voltage increased to approximately 1.2 times its pre-separation value and the apparent load increased immediately

after load shedding. Therefore, we confirmed that it was necessary to utilize Q balance control as well as P balance control.

August 2006 Incident

On August 14, 2006, another chance of the operation of the islanding protection was caused by damages on a 275 kV transmission tower crossing a river by a floating crane. A power station continued to supply power after successful operation of the islanding protection, when it was automatically shut down because the balance between the generation and load was lost due to increased demand in the morning. ■

8 Actual Data and Simulation Result (Voltage)



9 Actual Data and Simulation Result (Frequency)

