

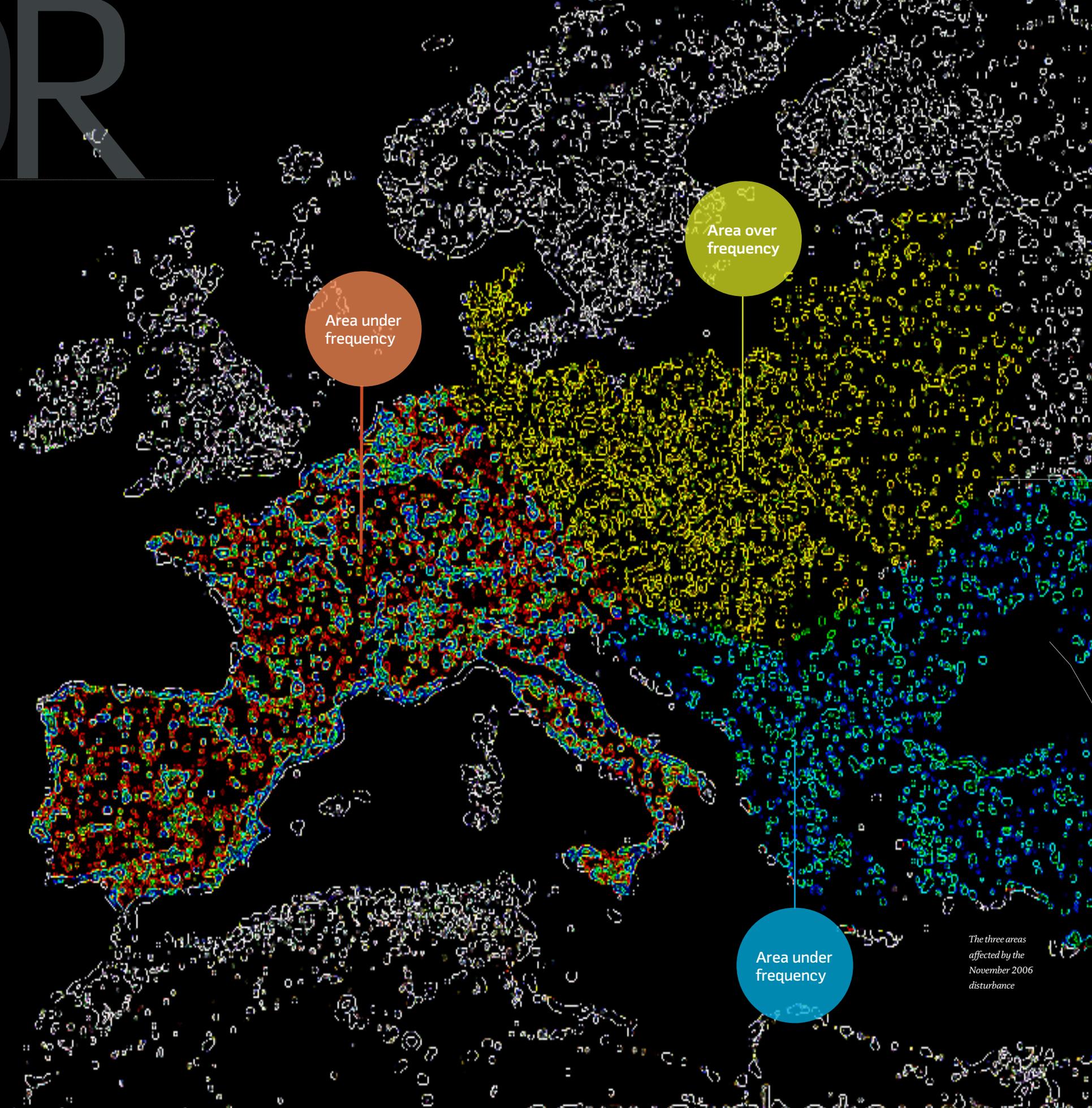


# MAJOR DISTURBANCE IN UCTE system

blackout

Europe

The Union for the Coordination of Transmission of Electricity (UCTE) grid suffered a severe disturbance on 4 November 2006. Immediate action by TSOs prevented a Europe-wide blackout. This article summarizes the findings <http://www.ucte.org> from the subsequent UCTE investigation.



*The three areas  
affected by the  
November 2006  
disturbance*

# SEQUENCE OF EVENTS

## Evolution of system conditions before system splitting

**21:29** E.ON Netz load flow calculation and N-1 empirical evaluation did not indicate any violation of limit values for the 380kV double circuit Diele-Conneforde line switching.  
**21:30** RWE TSO's load flow calculation and N-1 analysis confirmed that the grid would be highly loaded but secure.  
**21:38** E.ON Netz switched off first circuit of the 380kV Diele-Conneforde line.  
**21:39** E.ON Netz switched off second circuit of the 380kV Diele-Conneforde line.  
**21:39** E.ON Netz received warning messages about high power flow on the Elsen-Twistetal and Elsen-Bechterdissen lines.  
**21:41** Switching of the Diele-Conneforde line resulted in a significant increase (600MW) in the power flow on the 380kV Landesbergen-Wehrendorf line

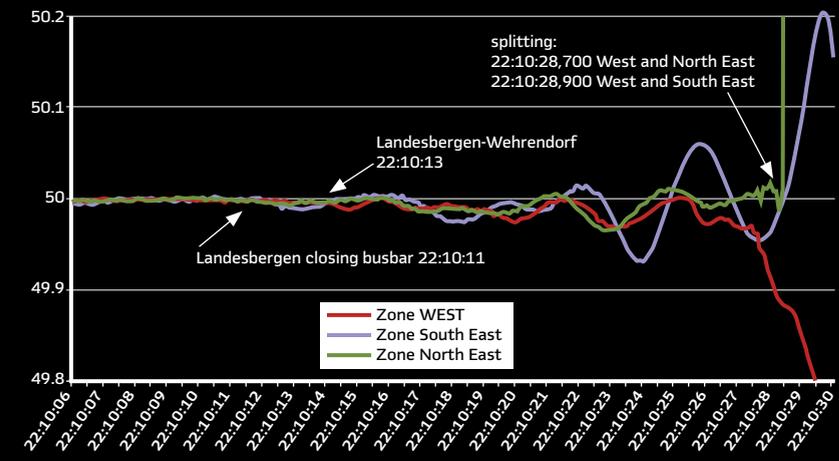
(interconnection between E.ON Netz and RWE TSO). RWE TSO informed E.ON Netz about the safety limit of 1,795A on this line although current was still below the limit and the N-1 criterion was being met in the RWE TSO network at that time. Protection settings on both sides of the Landesbergen-Wehrendorf line are different (see Table). Despite previous settings data exchange among TSOs, E.ON Netz claimed they were unaware of the differences and did not take the actual Wehrendorf (RWE TSO substation) values into account.  
**21:46, 21:50 and 21:52** Telephone calls between E.ON Netz, RWE TSO and Vattenfall Europe noting tight situation. Between **22:05 and 22:07** Load on the 380kV Landesbergen-Wehrendorf line exceeded RWE TSO's alarm level of 1,795A.

**22:08** RWE TSO requested E.ON Netz to intervene to restore safe grid operation. E.ON Netz's empirical assessment of corrective switching measures suggested that coupling the busbars in Landesbergen substation would reduce current. They initiated this switching at 22:10 without coordination with RWE TSO. Contrary to expectations the line current increased. Wehrendorf substation (RWE TSO) protection tripped and triggered cascade tripping all over the UCTE area. UCTE Separation The UCTE system split into 3 areas at **22:10:28**. The interconnection between Morocco and Spain tripped on low frequency at **22:10:32**. Figure 1 shows the frequency in the 3 areas from **22:10:06 to 22:10:30**. Time stamps of key events are

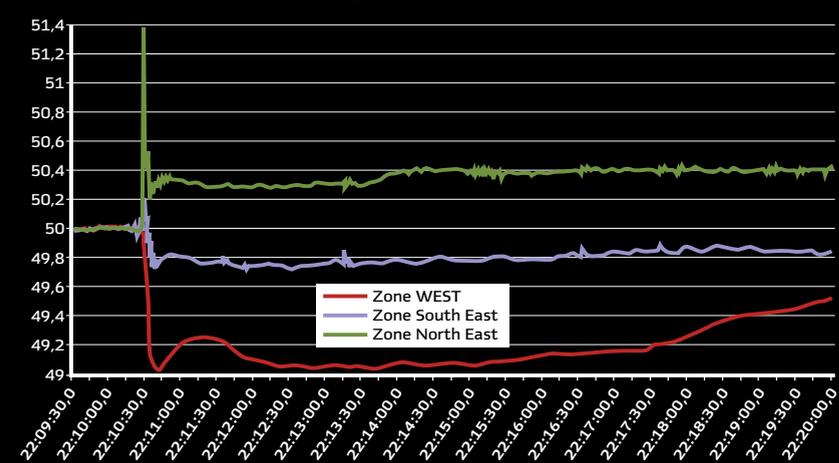
## splitting

indicated. Figure 2 shows the frequency for the 3 islands from **22:09:30 to 22:20:00**. The split caused a power imbalance by cutting 9,500MW power transfer from the East to the Western area which induced a frequency drop to 49Hz in the West. The corresponding power surplus in the North East increased the frequency to 51.4Hz. The split caused an 800MW power deficit in the South East area inducing under-frequency of 49.7Hz. Resynchronization A number of resynchronization attempts took place, however the first successful reconnection between the West and North-East areas was completed at **22:47:11** on the 380kV Bechterdissen-Elsen line. The resynchronization was completed when the last 400kV line between Croatia and Hungary was switched in at **22:57**.

1 Frequency recording until area splitting



2 Frequency recording after the split



3 Current limit values on the line Landesbergen-Wehrendorf

	E.ON Netz (Landesbergen)	RWE TSO (Wehrendorf)
Steady state value (thermal capacity of the line)	2000A	2000A
Warning value (alarm)	1000A and 2000A	1795A (90% of maximum limit value)
Maximum accepted value	2 550 A (85% of tripping current) for a maximum time 1 hour	1995 A (95% of the tripping current)
Tripping current	3000A	2100A

### Summary of Disturbance

E.ON Netz was requested to disconnect the double circuit 380kV line Diele-Conneforde in Northern Germany on 5 November at 01:00. E.ON Netz's empirical analysis showed no violation of the N-1 criterion from the proposed switching in its network. On 27 October E.ON Netz provisionally approved the switching request and informed neighboring TenneT and RWE TSO. Results of their N-1 analysis confirmed that the grid would be highly loaded but secure. The manual switching of the Diele-Conneforde line on

4 November caused increased power flow on the Landesbergen-Wehrendorf line (interconnection between E.ON Netz and RWE TSO). Action taken to remedy the situation actually deteriorated line loading eventually causing it to trip. This triggered cascade tripping interconnecting grid (which covers 23 countries across Europe) into 3 islands (West, North East and South East – see page 33) causing significant power imbalances in each island. Initial power imbalances in the West induced a severe frequency drop interrupting power supply

to more than 15 million West European households. Sufficient generation reserves in the under-frequency areas (West and South East) allowed restoration of normal frequency in a relatively short time. Lack of control over generation units (quick reduction of schedules and automatic reconnection of wind generation) in the over-frequency area (North East) contributed to a deterioration of system conditions in this area (long lasting over-frequency and severe transmission line overloading) and complicated the process of restoring normal system conditions.

Full resynchronization of the 3 islands was completed 38 minutes after the system split and normal conditions were restored in all European countries in less than 2 hours.

### Results of Investigations

Analysis indicates 2 root causes and 6 critical factors.

#### Root Causes

- N-1 criterion security rule
- Switching off the 380kV Diele-Conneforde line resulted in non N-1 secure conditions in the E.ON Netz grid and on some tie-lines

The N-1 security rule aims at avoiding cascading effects and requires that a single incident should not jeopardize the secure operation of the interconnected network.

to neighboring TSOs. E.ON Netz relied on an empirical evaluation and did not perform a numerical analysis of N-1 criteria.

E.ON Netz coupled the busbars in the Landesbergen substation in an effort to reduce the loading on the Landesbergen-Wehrendorf line. This was done without numerical analysis of the impact of this change on the power flow. The result was contrary to E.ON Netz's empirical assessment. It caused the line to trip triggering the cascade tripping that split the grid.

#### ■ Inter TSO co-ordination

Relevant neighboring TSOs checked N-1 compliance with the proposed 380kV Conneforde Diele line switching during the planning stage but a late switching change was not communicated in a timely manner by E.ON Netz to other TSOs. Despite the fact that the network was highly loaded, E.ON Netz did not prepare efficient remedial action to keep a minimum safety margin and prevent possible power flow increases.

Prior to the triggering event at the Landesbergen substation E.ON Netz did not fully coordinated with TSOs. No account was taken of different protection settings on either side of the Landesbergen-Wehrendorf line (i.e. on E.ON Netz and RWE TSO systems).

#### Critical Factors

##### ■ Generation related issues

A significant amount of generation (wind power, CHP) that tripped was connected to the distribution grid. Most TSOs do not have the real time data for these units. Frequency restoration requires sufficient means for rescheduling generation in individual control areas. Lack of control over generation units during the disturbance complicated the process of re-establishing normal conditions and was key to long lasting frequency deviations in the North-East and for re-synchronization failures.

■ Range of possible actions for the dispatchers to handle grid congestions

A limited number of measures are available to TSOs to manage emergency situations while also ensuring compliance with national regulations, market requirements and internal procedures. The adequacy of these measures needs further scrutiny.

##### ■ Defense and restoration plans

In some control areas, the DSOs started the re-energization of customers without proper knowledge of the overall situation in the UCTE system and without coordination with TSOs thereby hampering attempts to restore normal system conditions.

##### ■ Resynchronization

Actions taken by TSOs during the resynchronization process were not sufficiently coordinated. There were several unsuccessful attempts to resynchronize with only a partial view of the whole grid. Protection devices performed correctly and prevented further negative consequences.

##### ■ Training of dispatchers

The accuracy and completeness of dispatchers training was considered particularly in relation to (i) procedures and tools; and (ii) inter-TSO co-ordination under normal and emergency conditions. It was noted that dispatchers are not always trained on incidents that originate in external networks but affect their TSO network. It is not common practice to have joint simulation training with neighboring TSOs although there are discussions on procedures and exchanges of experience.

##### ■ Communication among TSOs

The communication among UCTE TSOs was as expected in an emergency situation given the current framework of co-operation, the scope of responsibilities of individual TSOs and on-line data available at individual control centers. However information about the actual state of the UCTE

system after splitting was not quickly available to all TSOs. The lack of information made it difficult for dispatchers to quickly and efficiently identify the source of the problem.

#### Recommendations

Following investigations into the disturbance, UCTE made the following recommendations and will report back at the end of 2007 on their implementation:

■ The application of the N-1 criterion in the rules of the UCTE Operation Handbook will be reviewed.

■ The rules on emergency operations will be extended with a "Master Plan" defining principles of operation and TSOs' responsibilities to manage UCTE-wide or regional disturbances.

■ UCTE will develop standard criteria for a regional and an inter-regional TSOs co-ordination approach aiming at improving the regional security management (from planning to real time).

■ UCTE will set up an information platform allowing TSOs to observe in real time the actual state of the whole UCTE system in order to quickly react during large disturbances.

■ The regulatory or legal framework has to be adapted concerning the control over generation output, requirements to be fulfilled by generators connected to the distribution grid, their schedules and access to online data.

Lack of control over distributed generation units complicated the restoration process

The second largest blackout in the history of TEPCO (The Tokyo Electric Power Company, Inc.) hit central Tokyo area at about 7:38 a.m. on August 14, 2006. It was caused by a **floating crane** on a barge going upstream on a river on the eastern edge of the city.

## Tokyo Blackout August 14, 2006

THE WORKERS ON THE BOAT DID NOT realize that the 33 meter crane was raised too high, so it hit TEPCO's 275 kV double circuit transmission lines that run across the river.

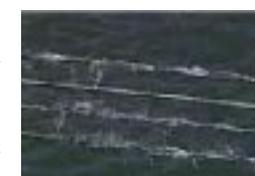
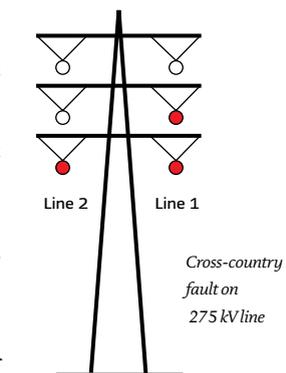
As a result of the accident the transmission lines were short-circuited and the wires damaged. The relay protection operated and tripped both lines. Power transmission was interrupted, resulting in a blackout that affected about 1.4 million households and offices during a very hot summer day. The transport network was disrupted, with passengers unable to use two lines on the city's largest subway operator, Tokyo Metro, for an hour to 90 minutes. There were no reports of injuries. The affected areas included the central part of Tokyo, northern part of Yokohama and western part of Kawasaki in Kanagawa, Ichikawa and part of Urayasu in Chiba. TEPCO immediately started trying to restore power supply to its customers. A Power Station continued to supply power until 7:58 a.m. after successful operation of a System Integration Scheme for the islanding, when it was automatically shut down because the balance between the generation and load was lost due to increased demand in the morning. About 174,000 households and offices were blacked out as a result. 59 minutes after the initial event, at 8:37 a.m., all substations were restored and resumed power transmission. Electricity supply to all TEPCO customers, except for two high-voltage customers, was



restored at 9:55 a.m. Supply to the two high-voltage customers was also restored at 10:44 a.m.

At this point in time, electricity supply to about 1,376,000 out of a total of 1,391,000 households and offices hit by the blackout was resumed, and the number of those customers hit by the blackout decreased to about 15,000 due to distribution equipment failure or incorrect settings. As for about 15,000 households and offices mentioned above, the power supply to them was interrupted by malfunctions of TEPCO's power distribution equipment, which were triggered by the floating crane that contacted the transmission lines. As a result of resolution of these malfunctions, the number of TEPCO customers that suffered from the blackout decreased to about 200 at 10:44 a.m. After four hours and forty-two minutes from the occurrence of the accident, power supply was fully restored at 12:20 p.m.

Floating crane that initiated the blackout



Damaged conductors



#### Biography

Shinichi Imai was born in Osaka in Japan, on January 11, 1964. He joined Tokyo Electric Power Company, Inc. after he earned his Master degree from Osaka University in 1989. After 12 years experience in power system operation & protection, his current position is Manager of Benchmarking group in the Power Network Division in TEPCO. His special fields of interest include power system protection, power system stability and Special Protection System. He is a member of IEEE and IEEJ (The Institute of Electrical Engineers of Japan). He has been involved in international technical activities such as IEEE PSDP and PSRC since 2004. He is a Vice Chairman of working group on Undervoltage Load Shedding in the IEEE Power Systems Relaying Committee. He is a registered Professional Engineer of the State of California.

#### Electricity

supply to about 1.4

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