Conclusion

The research on the development of a high-precision ac-dc transfer standard at ETL has been carried out by the following two stages. In the first stage, the ac-dc transfer standards of ETL have been re-evaluated using new standard TVCs which are traceable to PTB. Major improvement in the measurement uncertainty has been achieved by the suppression of the "off-time" effect. After the modification of the comparator circuit to avoid the off-time effect, the reproducibility of the measurement has been improved to a few parts in 10^7. Using a standard TVC calibrated by PTB with the uncertainty of 1.0 ppm(1σ), the best uncertainty of 1.2 ppm(1σ: at 10V,1kHz) has been achieved for the ac-dc transfer standards of ETL. In the CCE international comparison carried out in 1995, the values measured at the ETL have agreed with the values reported by the other countries at 1 ppm level, showing the international conformity of the ac-dc standards of ETL.

In the second stage of the research, the FRDC method has been developed as a basic reference for the ac-dc transfer standards. New modified waveform has been employed to improve the equality in RMS values for the dc- and ac-modes. In the case of modified waveform, the two major sources of the inequality in RMS values, i.e., switching transients and the high-frequency components, are compensated between the dc- and ac-modes. Hence there are no other sources of error which may contribute to the measurement uncertainty by more than 0.1 ppm. The agreement of the FRDC method with the standards based on MJTCs has further improved the reliability in the thermal ac-dc transfer standards at 0.1 ppm level. The FRDC method has been adopted at PTB, CSIRO/NML and KRISS/Korea, as one of the basic reference for the ac-dc transfer standards.

An important by-product of the FRDC method is the determination of time-constants of the thermoelectric effects in TCs. The thermoelectric effects are dominated by double-frequency thermal ripple in the case of sinusoidal waveform. On the other hand, since the FRDC source can produce an alternating voltage or current which generate steady-state-dc power, it is possible to detect the thermoelectric effects. Thus the FRDC method provides an effective experimental tool for the investigation of the thermoelectric effects in thermal transfer standards. From 1998, EUROMET started a project to circulate a FRDC source within the participating countries, in order to characterize the thermoelectric properties of the ac-dc transfer standards used in each national standard laboratory.

Other possible approaches for the realization of high-precision ac-dc transfer standard are under progress. At present, the most promising method may be the direct waveform syntheses based on Josephson D/A converters[24,40,41,53]. Since the unit of Volt is defined by the Josephson constant ($2e/h$), an ac waveform with precision equal to that of the dc-voltage standard could be obtained. A collaborative research between NIST and ETL is under way to realize a Josephson-based FRDC-DC measurement using the Josephson D/A converter[51]. Preliminary experiments[52, 58] have shown the possibility of determining the thermoelectric transfer difference with uncertainty better than a part in 10^7.

Another project to develop a Josephson D/A converter using SFQ pulses[42,43] has been initiated at ETL from 1997 [54-57]. One of the main goal of the project is to produce a sinusoidal waveform with precision better than a part in 10^7 until the year 2002. In the near future, the accuracy in the ac-dc standard may be improved to a part in 10^8 level by the realization of the Josephson ac-voltage standards.