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**2016 CIGRE-IEC Colloquium**
May 9-11, 2016
Montréal, QC, Canada

# Laboratory Investigation on the Effect of Wind on Corona of HVDC Lines

**F. H. YIN[1,2], M. Farzaneh[2]**
**[1]Canada Research Chair on Atmospheric Icing Engineering of Power Networks (INGIVRE) www.cigele.ca, Université du Québec à Chicoutimi**
**Canada**
**X. L. Jiang[2]**
**[2]State Key Laboratory of Power Transmission Equipment & System Security and New Technology, College of Electrical Engineering, Chongqing University**
**China**

## SUMMARY

As global power demand keeps increasing, the HVDC transmission market is growing at a high annual growth rate, being expected to reach 13.54 billion dollars by 2020. The reasons for choosing HVDC instead of AC to transmit large blocks of power in a specific case are numerous and complex. In fact, HVDC is more desirable from a technical point of view, as it is easier to control, requires a lower total investment, including lower losses, and is environmentally friendlier. Because of the present interest in HVDC transmission, a number of investigations on corona phenomena are being carried out all around the word. The main factors influencing the corona current and corona loss are the the surface gradient of the conductor, the ambient weather conditions, and the ambient electric fields produced by atmospheric electricity. Among the atmospheric variables, transverse wind is postulated to be a significant impact factor and has a large influence on the electric field and ion current environment of the transmission lines. The main objective of this study is to obtain information about the wind effect on DC corona. The experiments were carried out at CIGELE Laboratories, University of Quebec in Chicoutimi (UQAC). From the experimental results, it can be found that the corona discharges exhibited different colors when the applied voltage had different electrical polarity. Under fair weather condition, the effect of wind had minor influence on corona loss. However, in the presence of wind, the corona loss can be increased by 6-12% after corona onset under rain and icing conditions.

## KEYWORDS

Corona cage, corona loss, DC, effect of wind.

AndyYinEE@gmail.com

## I. Introduction

With the ever increasing energy demand for electricity, many high voltage transmission lines are being constructed. Recently, the HVDC transmission market is growing at a high annual growth rate, being expected to reach 13.54 billion dollars by 2020. The application of HVDC technologies for electric power transmission has some technical and economic advantages over HVAC transmission. Firstly, HVDC transmission lines have simpler requirements for line tower construction in comparison with HVAC transmission lines, and also lower per-unit costs, including costs per km of line and per MW of transmitted power. Secondly, it costs significantly lower for cables of the same transfer capacity as compared to HVAC lines. Moreover, additional reactive power compensators are not necessary when using long HVDC transmission lines. At sufficiently high level of surface electric field, complex ionization processes take place in the air surrounding high-voltage transmission line conductors, resulting in discharge phenomena known as corona [1-2]. The corona phenomenon is one of the most important issues associated with HVDC transmission lines. Because of the present interest in HVDC transmission, a number of investigations on corona phenomena are being carried out all around the world [3-9]. The main factors influencing corona loss are the surface gradient of the conductor, the ambient weather conditions, and the ambient electric fields produced by atmospheric electricity. Among the atmospheric variables, corona loss is thought to be negligible in fair weather but can be significant under rain and icing conditions. As transverse wind is postulated to be a significant impact factor and has a large influence on the electric field and ion current environment of the transmission lines, the main objective of this study is to obtain detailed information about the wind effect on DC corona under various weather conditions such as fair weather, rain, and icing.

As wind varies in velocity and direction even over short time periods in outdoor studies, it is very difficult to separate the effect of wind from others. Thus, the experiments were carried out in a climate room based on a corona cage at CIGELE laboratories, University of Quebec in Chicoutimi (UQAC). One of the major advantages of using a corona cage in the climate room is that under controlled laboratory environments, various weather conditions can be easily achieved and the environmental parameters can be kept constant during the experiments. Furthermore, the close distance between the tested conductor and the grounded meshed cylinder can replicate the surface electric field of a practical transmission line at a much lower applied voltage.

## II. Experiment Setup

### A. Climate Room

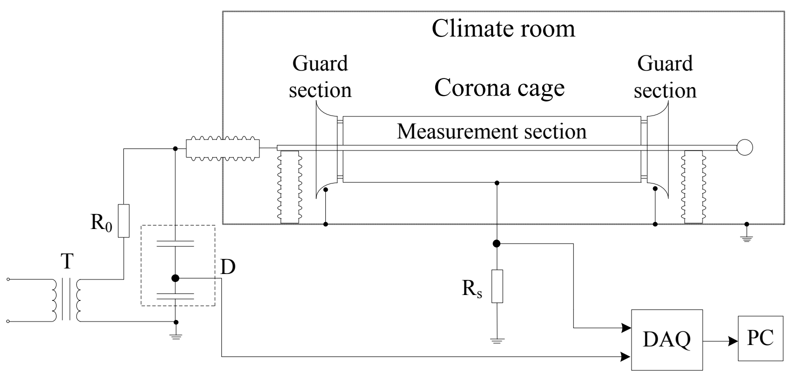



Fig. 1. Experimental setup

The experimental investigations were carried out in an 8.3m×5.8m×3.85m (length×width×height) climate room. The experimental setup is displayed in Figure 1. The climate room consisted of a cooling system, water spraying system, and wind controlling system. The high voltage was supplied through a DC source of 300 kV/600 kVA. The cooling system can regulate the minimum air temperature in the climate room down to -30 ℃ by a proportional integral and differential system (PID) with a precision of ±0.2 ℃. A system of oscillating nozzles was mounted on a pressure-fed water spraying system to produce the spray. Each oscillating nozzle consisted of an air and fluid cap. Water and air were supplied to the fluid cap under pressure and then mixed internally to produce a completely atomized spray. The climate room was equipped with a wind generator. The air generated by the fan passed through a diffusing honeycomb panel to yield a uniform wind velocity. The wind velocity can be controlled by frequency converters.

### B. Laboratory Corona Cage

The corona cage was constructed in the climate room as shown in Figure 2. A smooth aluminum tube with a diameter of 32 mm was placed concentrically inside another metallic mesh cylinder which had a diameter of 1 m. The aluminum tube was supported and fixed by two post insulators. For an indoor corona cage of finite length, the surface electric field of test conductor is uniform over the central section but become non-uniform at both ends. If guard sections had not been used at both ends of the cage, the cage length should have been at least three to five times longer to obtain a uniform surface field distribution along the central section of the conductor. As the dimensions of climate room was limited, two guard sections, each with a length of 0.3 m, were added at both ends to reduce the necessary cage length in the present experiments. The central measurement section in Figure 2 had a length of 2 m. As the measurement section was used for corona measurement, it was insulated with the guard sections. The measurement section was grounded through a non-inductive resistance $R_s$ (1 kΩ) which was in series with the corona cage while the two guard sections were connected directly to ground. As the electric field at the right end of the bare conductor was very high even with low applied voltage, a corona sphere was mounted there to prevent corona discharge at that end.

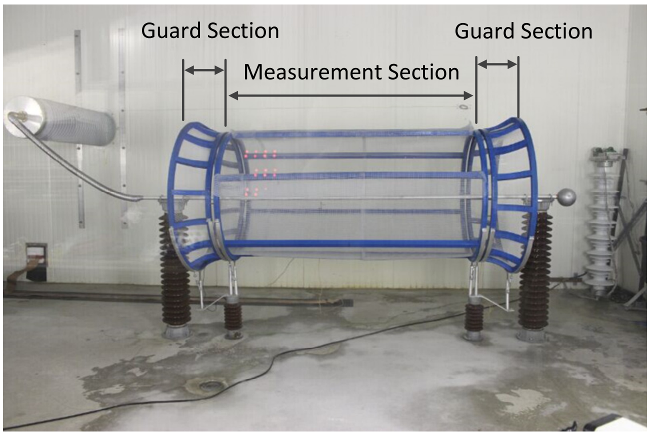



Fig. 2. Laboratory corona cage

Considering that the conductor and corona cage were constructed in a coaxial cylindrical system, the theoretical electric field at the surface of conductor $E_{surface}$ (kV/cm) can be calculated by the following formula

$$E_{surface} = \frac{U_{app}}{r_c \ln(R/r_c)} \quad (1)$$

where $U_{app}$ (kV) is the applied voltage, $R$ and $r_c$ are the radii of the meshed cylinder and conductor respectively, in cm. Given the radius of conductor, the calculated voltages corresponding to different electric strength levels are shown in Table 1. Unless otherwise noted, the values of the surface field strength mentioned in this paper are the surface field strength of the conductor before rain or ice is accreted on its surface.

**Table 1.** Surface Field Strength and the Corresponding Voltage for the Tested Corona Cage Configuration

| | 5 kV/cm | 10 kV/cm | 15 kV/cm | 20 kV/cm | 25 kV/cm | 30 kV/cm | 35 kV/cm |
|---|---|---|---|---|---|---|---|
| Voltage (kV) | 27.5 | 55.1 | 82.6 | 110.1 | 137.7 | 165.2 | 192.8 |

### C. Data Acquisition and Processing System

The value of voltage at which corona discharge starts is called the corona onset voltage. When applied voltage is higher than corona onset voltage, corona discharge is induced. The corona loss is generated mainly because of the creation and movement of positive and negative ions. Electrons created in the corona discharges have very short lifetime and the current pulses produced by their rapid movement do not contribute significantly to corona loss. As the corona pulses have little influence on corona loss, their contribution is not discussed in this study.

It is relatively simple to measure the DC corona loss [10-11]. Since practically all the current flowing between the conductor and the outer metallic mesh cylinder is due to corona discharge, the corona loss $P$ can be obtained by multiplying the voltage $U$ applied between conductor and the outer metallic mesh cylinder by the current $I$ induced by the applied voltage.

$$P = U \cdot I \quad (2)$$

In the present study, the instantaneous voltage and current were obtained through a voltage and corona current acquisition system. As illustrated in Figure 1, the capacitive voltage divider was used to collect the voltage applied on the conductor. The corona current between the conductor and the metallic mesh cylinder was obtained by dividing the voltage applied on $R_s$ by its resistance. Both the voltage and corona current values were sampled simultaneously by a NI PCI-6251 data acquisition (DAQ) board which has a sampling rate up to 1 M samples/s. The sampled values were transmitted by coaxial cables for noise reduction reason and then were stored electronically in a computer's memory by LabVIEW. With the voltage and current being known, the corresponding corona loss can be calculated by Equation (2).

## III. Test Procedure

A microprocessor-based versatile instrument, OMEGA HHF710, which combines relative humidity, temperature, and air velocity measurements into one highly versatile instrument, was used to measure the relative humidity, temperature and air velocity during the measuring period.

To investigate the wind effect on DC corona loss, the applied voltages were varied to get a corona loss curve against different electric field strengths. However, one of the problems in measuring corona loss at different voltages is the loss stabilization, especially under DC condition [12]. When the applied voltage increases, the corona loss reaches a temporary maximum at the new voltage level and then stabilizes at a lower value of corona loss. On the contrary, when the applied voltage decreases, the corona loss reaches a temporary minimum and then stabilizes at a higher value. However, the final values of two approaches are almost the same. As the stabilization process is longer for the increasing method, the decreasing method was adopted in this study. The voltage was firstly raised up beyond the expected corona onset voltage. After stabilization, a successively lower voltage was followed slowly. The time required for stabilization varies under different conditions. When the air is very dry, the stabilization time can be up to 10 minutes. Under rain or high humidity conditions, the stabilization time can be shorted to less 1 minute according to our experimental experience.

The test procedures are described as following.

*A. Fair weather*

For fair weather, as the humidity and relative air density have only a minor influence on corona loss [9][11], no specific humidity was required in the experiments. The climate room was firstly regulated to a preset temperature set by PID. Then, the fans were turned on to generate the desired wind velocity. After that, the corona losses were measured at different voltages. During the corona loss measurement, after corona loss was measured at a certain voltage, ten minutes were spared for stabilization after the voltage was changed for another corona loss measurement.

*B. Rain Condition*

The climate room was firstly adjusted to the preset temperature set by PID. Fans were then turned on to generated desired wind velocity and liquid system was opened. After that, the corona losses were measured at different voltages. Under the rain condition, one minute was spared for stabilization before each corona loss measurement.

*C. Icing Condition*

The climate room was first cooled down to a preset temperature set by PID. After the preset temperature was reached, it was followed by one hour for stabilization. After the preset temperature was reached, fans were turned on to generate the desired wind velocity and it was followed by one hour for stabilization. Then, the voltage was applied to the conductor to yield the desired surface field strength level. After that, the liquid system was opened and the fans were turned on simultaneously to generate the anticipated wind velocity. The ice accretion process lasted 40 minutes. After ice accretion, the liquid system was closed for corona loss measurement at different voltages. Under icing condition, one minute was spared for stabilization before each corona loss measurement.

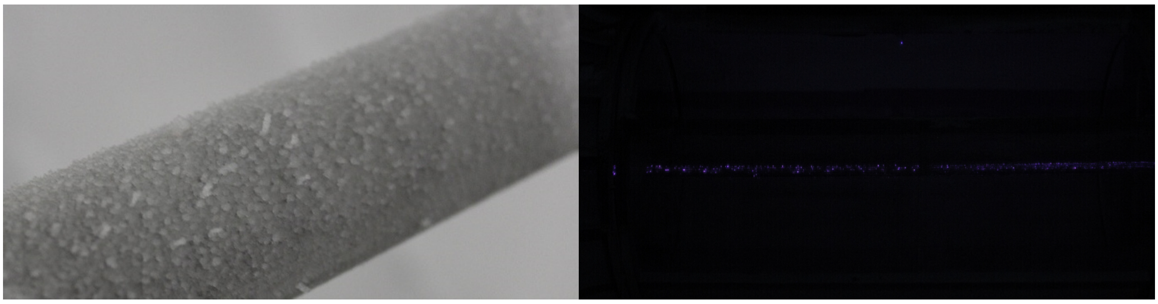
**Table 2.** Environmental Parameters.

| | Dry | Rain | Rime |
|---|---|---|---|
| Ambient air temperature (°C) | 12 | 5 | -15 |
| Water droplet size (μm) | 38 | 38 | 38 |
| Freezing water conductivity (μS/cm) at 20 °C | 50 | 50 | 50 |
| Wind velocity (m/s) | 2 | 2 | 2 |
| Precipitation rate (mm/h) | 15 | 15 | 15 |

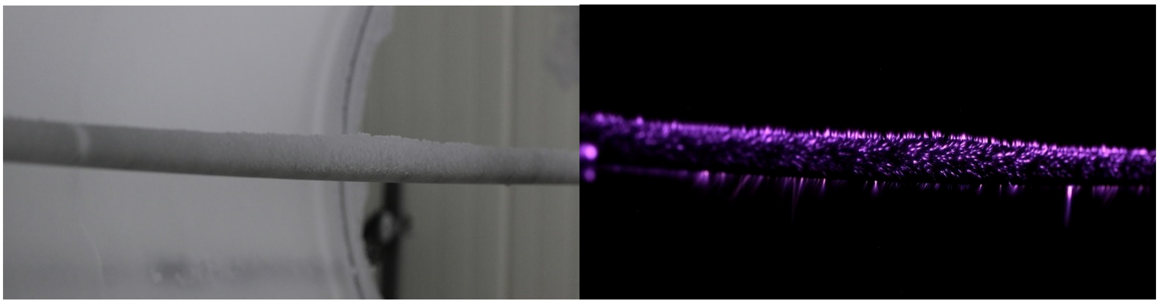
The environmental parameters are listed in Table 2. As corona discharge is a very complex process and its formation can be greatly influenced by the variation of environmental parameters, it is very important that the weather parameters are kept constant during the rain, ice accretion, and measurement process. With careful control, the measurements carried out in the CIGELE climate room were found to be repeatable and the accuracy of the corona loss measurements was satisfactory.

## IV. Results and Discussion

### *A. DC Corona Discharge Appearance*



(a) DC+ corona discharge



(b) DC- corona discharge

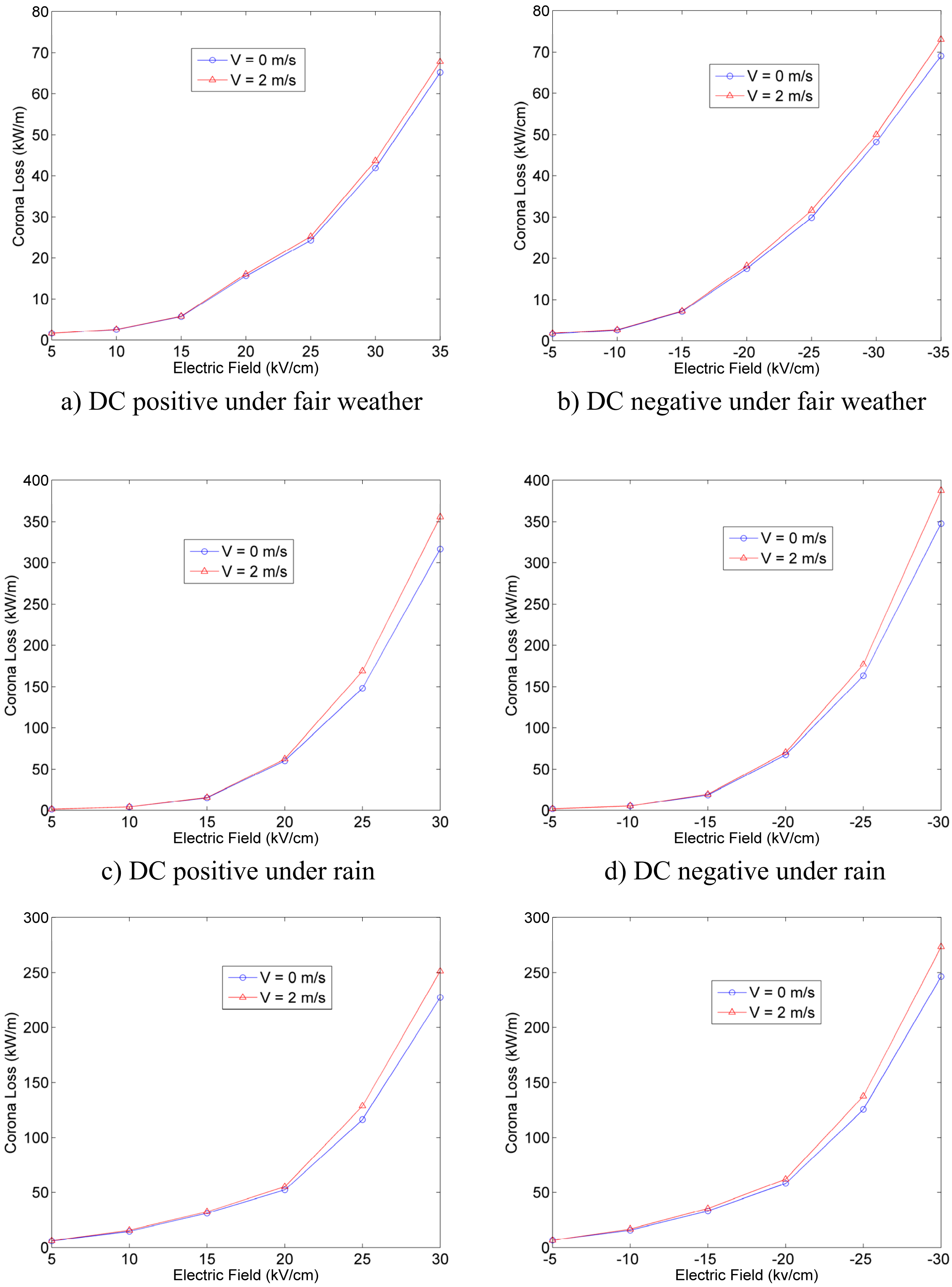
Fig. 3. DC corona discharges

Figure 3 shows the ice accreted when the conductor was subjected to ±137.7 kV, which was equivalent to 25 kV/cm as calculated by Equation (1), during the ice accretion process. From Figure 3, it can be noticed that the corona discharge of DC negative is more intensive than that of DC positive. With the applied voltage increasing beyond the corona onset voltage, smooth bluish-white glow was observed when the conductor was subjected to DC positive and reddish tufts were formed when the conductor was subjected to DC negative.

### *B. Effect of Wind on Corona Loss*

The relationships between corona loss and electric field strength under various weather conditions are plotted in Figure 4. Figures 4(a) and 4(b) show the corona losses at different DC electric field strengths under fair weather condition. From these two figures, it can be seen that corona loss is only a little higher when wind velocity is 2 m/s than when it is equal to 0 m/s for both positive and negative conditions. As the surface gradient for a practical HVDC transmission line does not exceed 20 kV/cm, corona loss is not more than 18 W/m in fair weather. Thus, corona loss is of no particular interest under fair weather condition. From Figures 4(c) to 4(f), it can be observed that wind has little influence on corona loss when the applied voltage is below the corona onset voltage under rain and icing conditions. With the electric field increasing further, corona loss is higher in the presence of wind compared to its absence. This increase in corona loss is about 6-12% after the corona onset. The reason for this phenomena can be explained as follows. Since there are many positive or negative ions in the vicinity of the conductor after corona onset, the corona discharge can be inhibited. In the presence of wind, these charges will be blown away. As previously mentioned, corona loss is mainly due to the movement of positive and negative ions, the accelerated movement of charges by the wind favoring corona current and corona loss.

Due to the fact that the mobility of the negative ions ($1.7\times10^{-4}$ $m^2/V\cdot s$) is higher than that of the positive ions ($1.5\times10^{-4}$ $m^2/V\cdot s$) [13], in theory negative corona current and the corresponding corona loss are normally higher than those of positive voltage if the corona cage configuration and the magnitude of applied voltage are the same. This statement is confirmed by the experimental results shown in Figure 4.




a) DC positive under fair weather

b) DC negative under fair weather

c) DC positive under rain

d) DC negative under rain

e) DC positive under icing

f) DC negative under icing

Fig. 4. Corona loss vs. electric field strength under DC voltages

Peek concluded that the corona losses were greater in snow weather than any other weather conditions [1]. However, it can also be seen from Figures 4(c) and 4(f) that when hard rime was accreted uniformly, the corona loss can be lower than in rain condition.

## V. Conclusions

The present study investigated DC corona discharge and the effect of wind on corona loss. From the experiment results, following conclusions can be drawn:

Measured corona losses increases with applied voltage for both positive and negative conditions.

Corona discharges under positive and negative DC voltage are different. When the DC positive voltage applied on the conductor is beyond the corona onset voltage, a smooth bluish-white glow can be observed. However, when the applied voltage is negative, reddish tufts are formed.

Since negative ions have a higher mobility than positive ions, corona loss is higher for negative than positive ions  for the same applied voltage.

Under fair weather, the effect of wind on corona loss is minor. However, in the presence of wind, corona loss can be increased by 6-12% after corona onset under rain and icing conditions.

Because of the limitation of corona cage dimension, this study focused only on monopolar conductors. Due to the complex interaction between positive and negative ions, the effect of wind on bipolar conductors should be investigated in the future.

## ACKNOWLEDGMENT

This work has been carried out within the framework of the Canada Research Chair on Atmospheric Icing Engineering of Power Networks (INGIVRE) at the Université du Québec à Chicoutimi (UQAC), with the support of the National Basic research Program of China (973 Program: 2009CB724501/502/503).

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