Experimental activity and investigation of wet-snow accretion on overhead power lines in Italy

P. Bonelli, M. Lacavalla
ENEA Electricity System Research (ERSE), Environment and Sustainable Development (ASV)
Via Rubattino - 54, 20134 Milano (Italy), *pbonelli@erse-web.it*, *lacavalla@erse-web. it*
(http://www.erse-web.it/)

Abstract— **The wet-snow events are one of the most critical meteorological conditions that cause electric failures during winter season in Italy. The damages of the electric power lines can be direct or indirect: in the first case the ice load on conductors breaks the support of the wires; in the second case others elements close to the line, for example plants, fall into the tower lattice due to the ice load and wind force together. ERSE has started a specific research program in order to investigate this phenomenon, through an experimental activity designed to assess the accretion of ice on conductors during these events. This paper consists of three parts. The first one describes the collection of the field data and the criticality of some measurements. The second one is devoted to verify the wet-snow weather forecasting developed by ERSE. The final part concerns the study of sensibility of ice accretion models proposed by CIGRE and their applications to the field data.**

I. Nomenclature

RV (Recreational Vehicle), ACSR (aluminum stranded conductors steel reinforced), TTD (Technology of Transmission and Distribution Department - ERSE), NWP (Numerical Weather Prediction)

II. Introduction

IN recent years, wide areas of Italy, mostly at medium-low altitude (600-1000 m. amsl), have experienced wet-snowfall events, as defined by COST-727 [7], involving serious damages to power lines and electric failures [12], as shown in Figure 1. This altitude layer has an higher density of overhead power lines than urban areas. Moreover, the grid structure has less restrictive hardiness criteria than the lines at the highest altitude [3], [13], [14]. The cause of electric failure principally depends on the accretion of ice-sleeves on wires. This phenomenon is principally due to wet-snowfall events rather than to the in-cloud icing episodes.

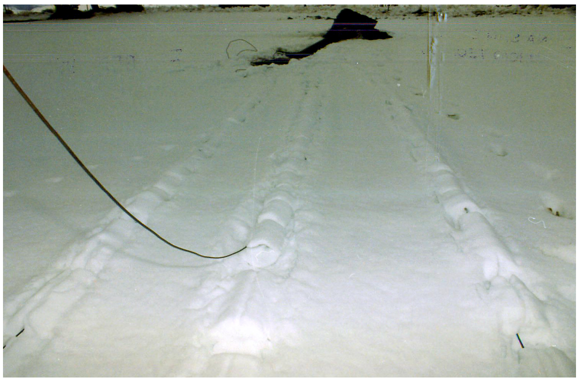

Figure 1: example of damages of Medium Voltage line crossing a hilly area in the north of Italy.

Unfortunately, no specific study has been carried out in Italy about wet-snow accretion on conductors until now. Some field experiments were carried out only for in-cloud icing [1].
For this reason, ERSE has started a specific research program devoted to:

- analyze long time series of standard WMO's data [8];
- collect field measurements;
- validate wet-snow accretion models;
- test weather forecast procedures.

In Italy, as in other countries [15][16], the extreme space-time's variability of this phenomenon makes a fixed test-site useless. Therefore, an experimental organization, based on mobile-campaigns, has been developed.

Mobile-campaigns have been done in different Italian sites during the winter 2007-2008, carrying instruments and operators to the location "where" and "when" a suitable wet-snowfall event was predicted with at-least two days in advance. For this purpose, an RV was equipped with light, "easy-to-install" instrumentation that includes:

- weather station;
- manual meteorological instruments;
- snowfall photo-detection system;
- different type of ACSR conductors;
- scale;
- gazebo;
- others outdoor-equipments.

The aim of the work is to describe the snowfall and ice-accretion on conductors at a local scale only for wet-snow conditions.
Snow accumulation models are developed by some authors in different countries like Japan and France [9], [10], [18], [20].
One of the main goals of this modeling effort is to provide a method for computing ice loads from standard meteorological records of temperature, wind and ground precipitation. Limitations in the models, as stated by different authors, rise from the lack of experimental data field that are necessary to tune the compulsory empirical scheme. Moreover, as it will be presented further, the model response to some standard meteorological variable is highly critical.
The data collected during the experimental campaign in Italy has been used in order to test two of the models proposed by the literature.
Recommendations about measurements and model applications are provided by the COST-727 WG2 Report [7] describing activities on icing measurements on structures in different European countries. In the field of Power Grid, the CIGRE Organization provides guidelines about measurements as well accretion models on overhead power lines [5], [6].

III. Experimental Campaigns

During the winter season 2007-2008, four strong snowfall conditions in different sites of Italy have been identified by 48 hours weather forecast. These areas have been reached soon by RV (camper) and all instruments have been installed. The experimental sites are represented in the map shown in Figure 2.

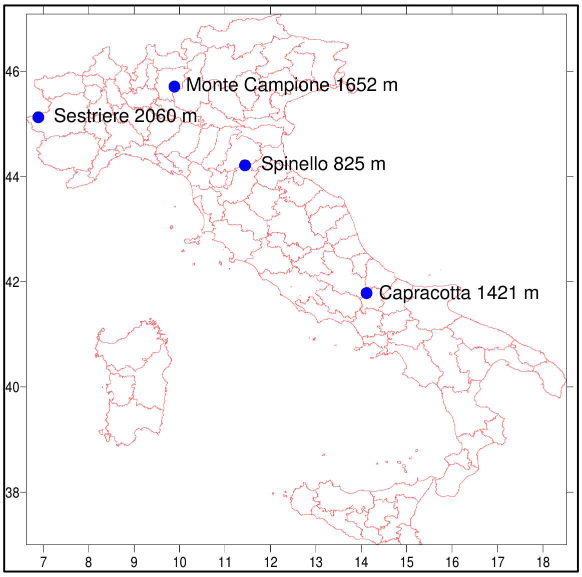

Figure 2: the map shows the position, the location and the altitude of the measurements sites.

A simplified block-diagram of campaign's organization is shown in Figure 3. It consists in two parts: the decision making that leads to the site's identification in the ERSE headquarter in Milan and the operational phase in situ, where the instruments have been installed and the measurements have been collected.

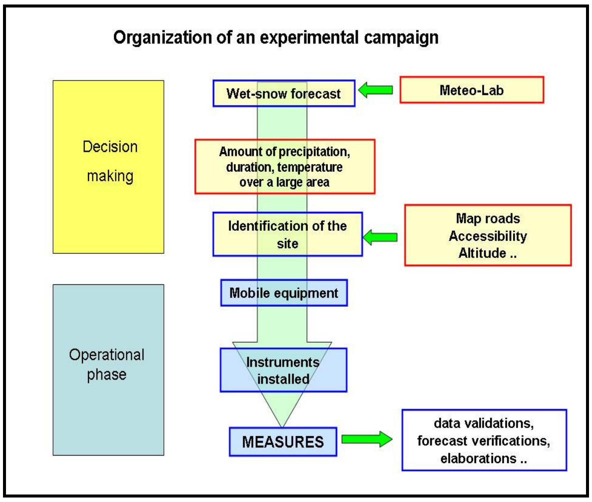

Figure 3: Block-diagram of the organization of an experimental campaign.

The test-conductors is composed by wire's supports where six specimens of ACSR (diameters: 15.8 mm and 31.5 mm) are settled, as shown in Figure 4. In this experimental activity, the conductors are not current-supplied and the joule-effect is not reproduced.
During the snowfall event, the snow thickness accreted on the conductors has been frequently manually detected. At the end of the snowfall episode, the ice-sleeve have been weighted.

Figure 4: the test-conductors was built by TTD Laboratory: conductors have a steel core with aluminum coating (ACSR). Wires are not current supplied.

The snowflakes falling velocity have been deduced by a photo detection system made of two dark panels, a light beam and a camera. A simplified scheme of the two measurement's systems is shown in Figure 5 and Figure 6.

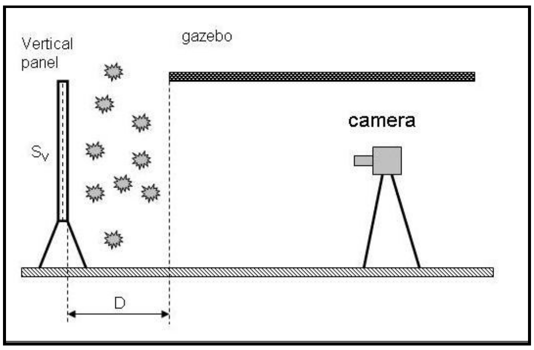

Figure 5: vertical panel used for flakes concentration measurements and vertical velocity.

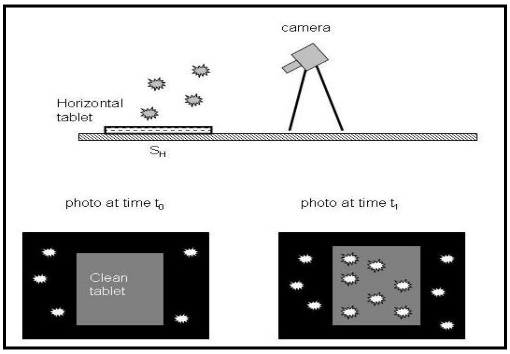

Figure 6: horizontal tablet used for flakes' measurements.

The two systems allow to estimate the vertical velocity by means of the flux on the ground (ϕ_S) that is computed by using the equation (1); where N_S is the number of the flakes accumulated on the horizontal tablet, S_H is the horizontal tablet surface, Δt the time step of tablet exposure. An independent way to estimate the flux is by means of the snowflakes concentration and it can be calculated using the equation (2), where N_V is the number of the flakes identified in the volume delimited by the vertical panel and the gazebo, S_V is the vertical panel area, D is the distance between gazebo and the panel and V_S is the flakes' falling velocity.

$$\Phi_s = \frac{N_S}{S_H \Delta t} \qquad (1)$$

$$\Phi_s = \frac{N_V}{D * S_V} V_s \qquad (2)$$

At last, it is possible to calculate V_S from the equality between (1) and (2) as indicated in the equation (3).

$$V_s = \frac{n_S}{n_V \Delta t} D \qquad (3)$$

where: $n_V = \dfrac{N_V}{S_V}$; $n_S = \dfrac{N_S}{S_H}$

This method is rather experimentally complex and it doesn't allow frequently measurements. It has been used only to compare the results of an easier method based on the shutter velocity of the camera, that consists to measure the length of the snowflake track on the picture and to divide it by the shutter time. Others studies about the snowflakes velocity are described in literature [2], [4] by using size, shape and density of flakes.

A general plan of the experimental site set-up is shown in Figure 7.

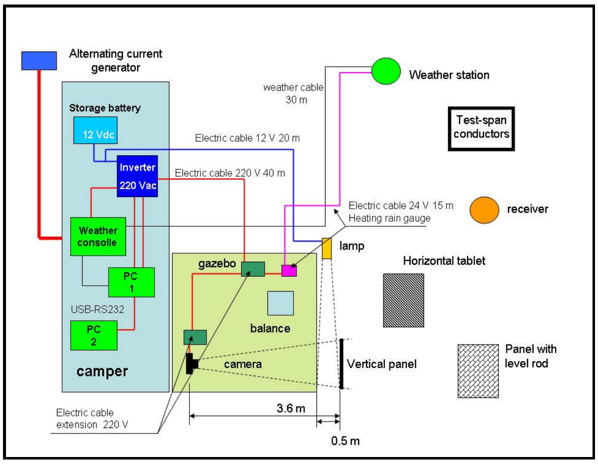

Figure 7: the RV (camper) measurements area where the instruments are settled.

A. *Weather data*

The weather station supplies the principal meteorological measurements: temperature, humidity, wind intensity and direction, amount of precipitation, as seen in Figure 8.
The rain gauge is heated by electric-resistance. The first problem is the little intercepting surface of the gauge during windy situations. The second one regards the accuracy of precipitation intensity depending on the snow melting velocity in the pluviometer. Others bucket larger than the pluviometer have been positioned on the ground to better estimate the amount of precipitation. Other problems are related to the instruments icing, especially the cup of anemometers. Additional manual measurements have been carried out in order to validate the automatic data.

Figure 8: weather station installed near to the conductors.

The principal weather observations for each campaign are summarized in Tab 1. In general, the durations of a wet-snow event were rather long, typically more than 24 hours. The relative humidity remained high (81-96%) during the wet-snow episodes. The air pressures registered and their variations, were characteristic of deep cyclone affecting the Mediterranean area in the winter season (~ 1015 mb). The total equivalent amount of precipitation was quite modest for

all snowfall events. Unfortunately, the first three campaigns had no wet-snow conditions because of the difficulty to match the right altitude and then temperature. Nevertheless, they were important to test the whole system.
In details, the total amount in Sestriere campaign was the lowest episode (9 mm). In general, the average temperatures were closed to the freezing point. The lowest temperatures were measured in Sestriere and Monte Campione sites, respectively -4.6 °C and -4.4 °C.
The average wind intensity remained low for all campaigns duration (< 6 m/s), but the presence of some gusts has been observed in Capracotta and Monte Campione snowfall events. Although these weather conditions, little snow accretions on the wires has been noted at every site except during the gusts.

Tab 1: Summary of the principal weather data collected during the four experimental campaigns in the winter season 2007-2008.

meteorological parameters	Sestriere	Monte Campione	Capracotta	Spinello
Date	21/11/07	10/01/08	05/03/08	06/03/08
Duration (h)	35	36	25	34
T avg (°C)	-3.9	-0.5	-2	-0.4
T max (°C)	-2.9	0.7	0.3	1.2
T min (°C)	-4.6	-4.4	-2.8	-1.9
99th perc. T	-3.1	0.7	0.2	1.1
90th perc. T	-3.4	0.4	-0.4	0.3
10th perc. T	-4.5	-1.9	-2.8	-1.3
R.H. max (%)	97	100	95	98
R.H. min (%)	92	81	88	96
P min (mb)	1012.8	1008.9	1012	1010.5
P max (mb)	1021.8	1017.9	1018	1015.5
W avg (m/s)	1.2	1.4	5.5	0.3
W max (m/s)	3.1	9.8	13	3.1
Gust (m/s)	4.9	14.8	15.6	6.3
99th perc. W	2.7	6.1	9.8	1.8
90th perc. W	2.2	3.6	8.5	0.9
10th perc. W	0.4	0.2	0.2	0.2
Dir med (°)	NE	NE	N	WNW
Rainfall (mm)	9	26.6	17.6	23.8

B. *Ice-sleeve data*

The wire's test-span has been installed on the site close to the weather station. The diameter and shape's measurements of ice-sleeves accreted on wires are shown in Figure 9. The snow accretion pictures has been carried out on the vertical direction (V) and on the horizontal one (H). At the end of the wet-snow events, the sleeves-ice accreted on wires has been weighted. An evaluation of sleeve-ice densities can be deduced by assuming that the ice-sleeve on the conductor is uniformly distributed along the span and cylindrical in form.

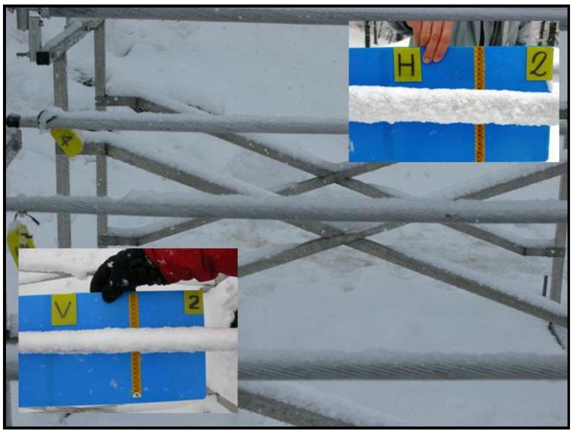

Figure 9: the ice diameter measurements. H is the shot on horizontal wire plane, V is on the vertical one.

The principal ice-sleeve measurements on the different types of conductors are summarized in Tab 2, where D is the ice sleeve's diameter and W is the weight of the ice-sleeve accreted on wires. Some conductors are free to rotate (FR) by using anti-friction ball bearings, the other ones are bounded to their support (BD). Few data are available for the Sestriere and Monte Campione campaigns, due to technical problems occurred during the events. Instead, all measurements have been leaded during the wet-snow episode at Spinello site. It is evident from the table that the greater ice-sleeves are those accreted on the largest diameter's wires. The maximum ice-load observed is 0.42 Kg/m on the FR ¤31.5 conductor. The average ice-sleeve density is about 0.32 g/cm^3, obtained by weight and diameter measurements.

Tab 2: ice-sleeve diameter (D) and weight (W) on different conductors.

Ice sleeve's data	Sestriere	Monte Campione	Capracotta	Spinello
D -FR ¤ 31.5	1 cm	3 cm	5 cm	**5.5 cm**
D -BD ¤ 31.5	-	2.5 cm	5 cm	**3 cm**
D -FR ¤ 15.8	-	-	2 cm	**2.5 cm**
D -BD ¤ 15.8	-	-	3 cm	**2.5 cm**
W -FR ¤ 31.5	-	-	-	**0.42 Kg/m**
W -BD ¤ 31.5	-	-	-	**0.10 Kg/m**

IV. WET-SNOW FORECASTING

Two NWP models are used for the wet-snow forecasting. The first one is the operational general circulation model by European Centre for Medium-Range Weather Forecast (ECMWF[1]); the second one is an non-hydrostatic Limited

[1] ECMWF: h. resolution: 0.25° (~30 km), 50 vertical levels.

Area Model (LAMI[2]) developed in the framework of the COSMO (Consortium for Small-Scale Modeling) Project and provided by ARPA-Emilia Romagna. The map, as you see in Figure 10, represents the Geopotential height and temperature at the 850 hPa-level for the Spinello event. It is evident that a deep low circulation pressure affects the Italian Peninsula with an important wet-advection (stau) against the Adriatic side of the Apennines. The temperature at the 850 hPa level is closed to -2 °C. These characteristics assure the optimum condition for observing a wet-snow event at the Spinello altitude.

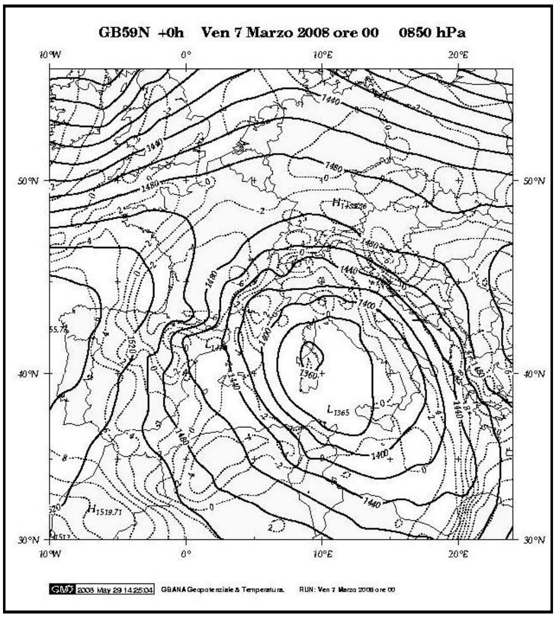

Figure 10: the maps shows the temperature and Geopotential height at 850 hPa. ECMWF forecast valid for 07-03-2008 (Spinello campaign).

A. Weather forecast procedure

The weather forecast procedure is developed by the Meteorology and Climate Research for the Electric Power System group (MEC) and the main steps are represented in Figure 11. The two models provide the principal meteorological parameters in the interval forecast ranging between +0 (the analysis) and +72 hours. The variables considered are the followings:

- Geopotential height at 500,700,850 hPa, SURF level
- Air temperature
- Total amount of precipitation
- Liquid water content of precipitation
- Wind intensity and direction
- Freezing point level
- Duration of snowfall event

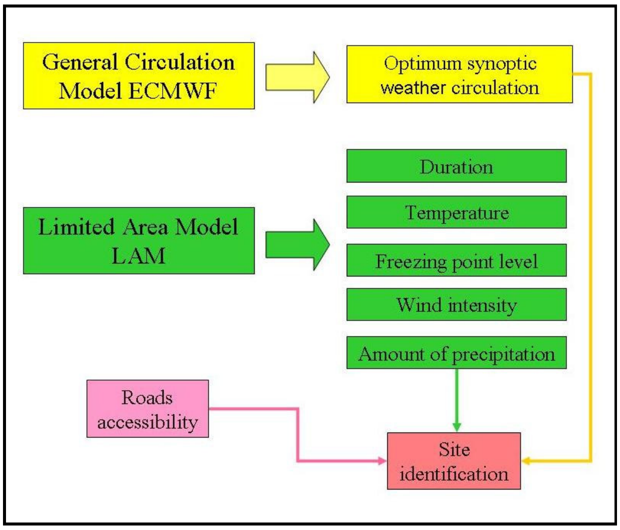

Figure 11: forecast procedure for the site identification, using the emissions of two numerical weather prediction models.

The interpretation of the general circulation model highlights the synoptic features that could be favorable for wet-snowfall events: for example a deep cyclone over Italy with wet-advection against a mountain ridge. The LAM model provides the local meteorological conditions that are necessary for evaluating the wet-snowfall's altitude, intensity, duration etc.. The LAM vertical profile of wind and temperature in the selected area, reveals the stability of the atmosphere. In the case of unstable saturated atmosphere, the convection is strong and we may expect heavy precipitations. Another important consideration concerns about the presence of a wet and warm intrusion above a colder air mass layer, which is a necessary condition for snow to form, and finally the surface air temperature must be slightly above 0°C.

B. Weather forecast verifications

The weather forecast verifications are necessary to estimate the reliability level of NWP models. Scatter plots between observations and weather forecast, issued one-day before wet-snowfall event, are presented. Scatter plots of air temperature and wind intensity are represented respectively in Figure 12 and Figure 13. In Figure 12, the forecast air temperature for Sestriere event is overestimated compared to the observations; instead of Monte Campione event in which the forecast temperatures are underestimated. Temperatures of Capracotta are rather scattered, whereas for Spinello episode the observed and forecasted data are well correlated. Wind scatter plot, as shown in Figure 13, reveals that observations were much higher than the forecast ones in Capracotta site; on the contrary wind forecasts overestimated the observations at Spinello and Monte Campione. Observations and forecasts are well correlated for Sestriere event.

[2] LAMI: h. resolution: 0.067° (~7 km), 41 vertical levels, domain: Italy

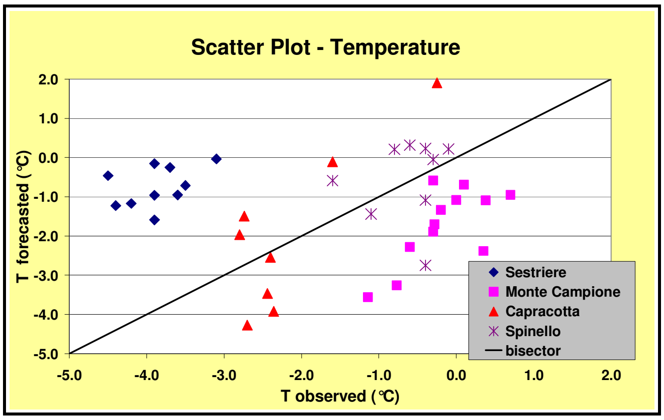

Figure 12: air temperature scatter plot.

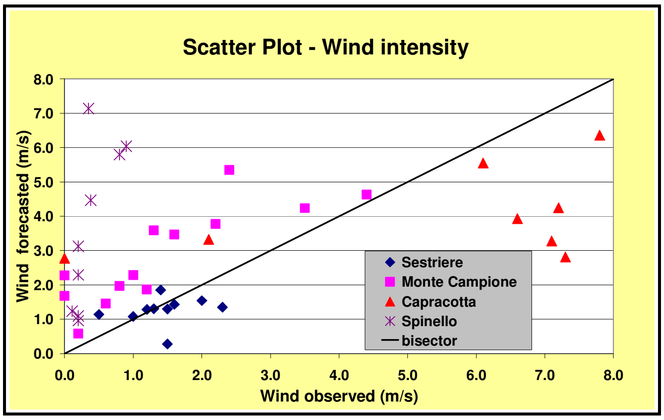

Figure 13: wind intensity scatter plot

Finally, the total amount of precipitation are summarized in Tab 3 for each snowfall's episode. As shown from the table, the observations and the forecast show good agreement, except for the Capracotta event. This difference is probably due to big errors in precipitation measurements because of the presence of strong wind.

Tab 3: observations and forecast of total amount of precipitation

Total amount Precipitation (mm)	Sestriere	Monte Campione	Capracotta	Spinello
Measured	**9**	**26.6**	**17.6**	**23.8**
Forecasted	*14.9*	*31*	*31.6*	*25.3*

V. WET-SNOW ACCRETION MODELS

The are two approaches to model ice accretion: the empirical and the physical one. In our research activity it has been tested the first approach, in which direct measurements or derived ones, have been used to estimate ice loads and diameters of ice-sleeve's accreted on conductor as shown in Figure 14. The two wet-snow models tested, are those proposed by CIGRE: the Japanese Cylindrical Sleeve Model and the French Cylindrical Sleeve Model.

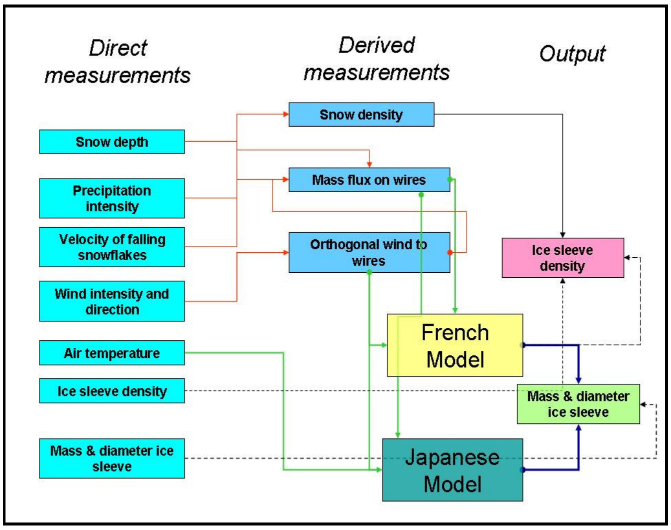

Figure 14: Flowchart used for the computation and comparison of the principal parameters involved in the wet-snow process.

In the Japanese model the snow accretion depends on the amount of snow passing around the wire having speed that is the sum of wind and falling velocity of snowflakes. When wind action is taken into account, the value of the intensity of precipitation P_n on the wire is approximated by the equation (4):

$$P_n = P\sqrt{1+\left(\frac{V\sin\theta}{V_s}\right)^2} \qquad (4)$$

where P is the intensity of precipitation observed on ground surface, V is the wind speed, V_s is the falling speed of snowflakes, and θ is the angle between the axes of wire and wind direction. Sakamoto obtained an empirical model using a limited dataset of observations. The model is synthesized in the following equation (5) that determines the mass of accreted snow per unit length of wire (W) in function of the time:

$$W = 4.5\frac{\exp\left\{-6(T/T_D-0.32)^2\right\}}{V_N^{0.2}}P_n t \qquad (5)$$

where T is the air temperature, V_N is the mean value of the normal components of the wind speed to the line and the equation for T_D is as follows equation (6):

$$T_D = 2.31 - 0.101\times\ln(H) \qquad (6)$$

where H is the sea level. As one can see, the model is independent by the wire radius.

The second model taken into account, developed in France, is based on the work of Admirat [9] performed in 1980's, partly in collaboration with Japan. In order to explain this model, it has been considered the general formulation introduced by Makkonen [20], where the mass accretion M versus time t is given by the equation (7):

$$\frac{dW}{dt} = \alpha_1 \alpha_2 \alpha_3 w v A \qquad (7)$$

where: A is the cross-sectional area of the object, w is the mass concentration of snow in air and v is the velocity of particles relative to the object. In the case of the French model of wet-snow, the high inertia of particles determines the collision efficiency $\alpha_1 = 1$, accretion efficiency $\alpha_3 = 1$.
The sticking coefficient is formulated in the following way:

$\alpha_2 = 1/Vn$ for $Vn > 1$
$\alpha_2 = 1$ for $Vn < 1$.

This formula is based on experimental results where Vn is the normal wind velocity. In general, the increase of radius (R_2-R_1) and mass (W_2-W_1) in a short interval Δt (t_2-t_1), can be deduced by the equation (7) and (4):

$$R_2 - R_1 = \overline{\alpha_2} \frac{\overline{P_n}}{\pi \overline{\rho}_S} (t_2 - t_1) \qquad (8)$$

$$W_2 - W_1 = \pi \overline{\rho}_S (R_2^2 - R_1^2) \qquad (9)$$

where ρ_S is the ice-sleeve density that is assumed to depend on snowflakes velocity normal to the wire (Vn) according to relation:

$$\rho_S = 100 + 20Vn \qquad (10)$$

A. Sensibility of wet-snow models

The wet-snow accretion models depend strongly on some input variable, as the air temperature and the wind intensity, a discussion about their sensibility is presented. The mass growth response for the Japanese model vs temperature, is a "bell curve" with the peak centered on 0.5°C, that quickly falls off towards zero for little temperature's increase or decrease. Two Japanese growth's curves are shown in Figure 15 and Figure 16, respectively at the doubling of the snowflake falling velocity (Vs) and at the doubling of the normal components of the wind speed to conductor (Vn). The Vs values used in the graph are typical: the 1 m/s value is generally used in literature when it is not available from measurements; the 2 m/s value has been recorded during the campaigns. The Vn values used in the second graph are commonly observed during snowfall events. Both graphs are computed for P = 1 mm/h.

The high variation shown in the two graphs, caused by air temperature, is due to the model formulation, instead of the Vs and Vn variations that mainly depend on the "geometric" equation (4) where the ground precipitation (P) is supposed to be constant. Vn is present also in the (5) but it has little influence. The sensibility of the models shown above, demonstrates the importance of high accuracy on weather measurements for assessing ice loads on wires by means of the Japanese model.

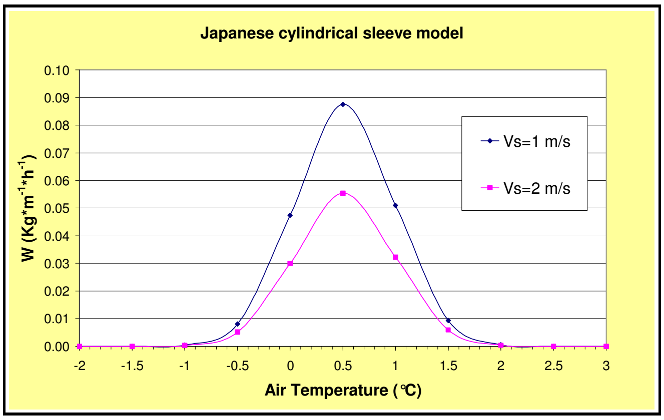

Figure 15: "bell curve" of ice-sleeve's growth on a conductor vs air temperature, at doubling the falling speed of snowflakes (Vs).

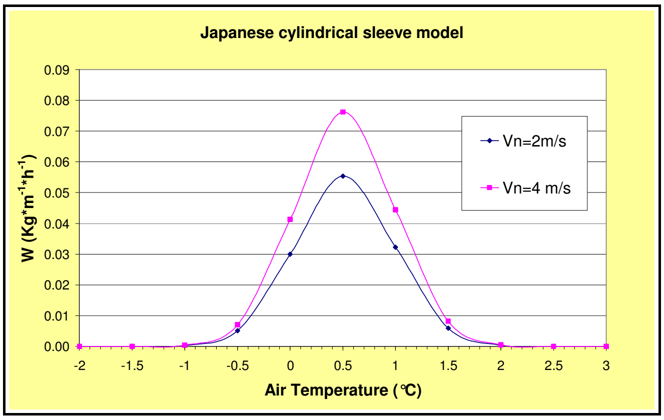

Figure 16: "bell curve" of ideal ice-sleeve's growth on a conductor vs air temperature, at doubling the normal components of the wind speed to the wire (Vn).

In the French cylindrical sleeve model, as it is shown on Figure 17, the mass growth (W) depends on the normal wind (Vn) for low values, having a maximum at 1 m/s and then at highest wind values it remains quite constant. All the values are direct proportional to the ground precipitation rate (P). No dependence by the temperature is considered by this model. Comparing the mass accretion from the two model, it is evident that the Japanese model is more dependent by the wind velocity than the French one.

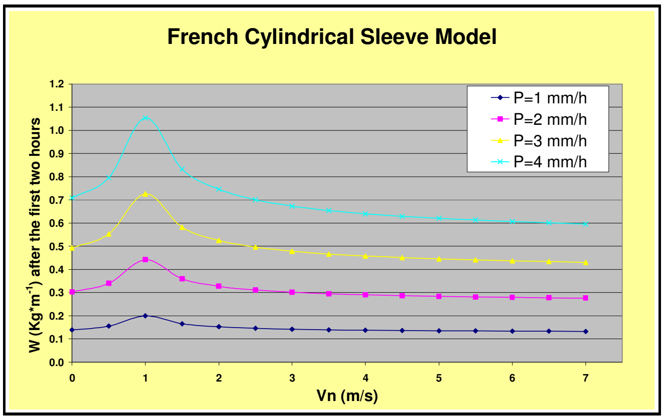

Figure 17: curves of ideal ice-sleeve's growth (in mass) after two hours vs the normal wind speed (Vn) at different precipitation intensities (P).

B. Application of wet-snow models to field data

The two wet-snow models analyzed, are applied to the field data collected only for the Spinello experimental campaign, in which the data set is complete and the largest accretion was observed. The two free to rotate conductors (FR-1 and FR-2 with the same diameter ¤31.5 mm) are considered, because the smaller ones are affected by partial sleeve's detachments due to their high bend. The ice-sleeve measurements and simulations by Japanese and French models are summarized in Tab 4.

Tab 4: ice sleeve's measurements and simulations by using the two models.

Measurements and simulations	**W (kg/m)**	**ρ_s (kg/m^3)**	**radius (cm)**
measurements on FR-1	**0.38**	**90**	**4.0**
measurements on FR-2	**0.42**	**86**	**4.3**
Japanese Model Simulation	*0.20*	-	-
French Model Simulation (with α_2 = 1; Vn<1)	*1.74*	*105*	*7.3*

Applying the Japanese model, it is evident the underestimation of the ice-sleeve weight. The temperature during the event ranges between -0.3 and -0.8 °C, with an average value of -0.5 °C, this is confirmed by other independent measurements. One can notice that the sensibility of the model to this variable will lead to fit the measured weight just forcing a constant temperature of -0.2 °C.
Others hypothesis related to measurement's errors are excluded for the following reasons:

- the total amount of precipitation was well measured (two different gauges were used);
- the wind was almost absent;
- the snowflakes' velocity was well estimated;

Applying the French model, some considerations can be made regarding to:

- the sticking coefficient α_2 ;
- the measured and calculated density of ice-sleeve (ρ_s);
- the radius of ice-sleeves by the (8);
- the weight of ice-sleeves by the (9).

The coefficient of α_2 is calculated, both for the big wire and for the small one inverting the equation (8) and using the field data as input. The α_2 value for big wires (0.52) is greater than the small ones (0.2). In fact, observations confirmed that the greater bend of little wires reduces the sticking efficiency of snowflakes hitting the conductors.
The measured density of ice-sleeve were compared with the ones calculated by the equation (10). The measured are lower than the estimated values by a 15%.

Finally, it is estimated the radius and the mass of ice-sleeves accreted on wires, by the equations 8 and 9 respectively. Always the French model overestimates the thickness and the weight of ice-sleeves, this is principally due to the formulation of α_2 rather than the ice density one.

VI. Conclusions and future developments

This paper has presented the experimental activity and investigation of wet-snow accretions on conductors made in Italy during the winter season 2007-2008. This research has allowed to:

- observe in detail the physical process leading to ice-sleeve accretion on wires during some wet-snow events;
- apply forecast procedures, developed to identify the wet-snow conditions, and verify them by the weather parameters collected;
- test the reliability of wet-snow models proposed by literature with the field data collected;
- draft some guidelines for accurate field measurements during the snowfall conditions.

The first consideration is that mobile campaign can be organized using at least +48 hours forecasts with a good accuracy in the 3D temperature variable. A list of selected sites, accessible by RV, at different altitude, must be set before the campaign season. In such way it is possible to better focus the weather forecast.

Final consideration about the accretion models cannot be done considering the few data collected, but some remarks about this work are related to:

- the extreme sensibility of a model to the air temperature can produce large differences between computed and observed ice-sleeve;
- the formulation of sticking coefficient in the French model may be better adapted to local condition;
- perhaps other important physical parameters must be taken into account in the models as the snowflakes dimensions, concentrations , etc...

The experimental work will continue next winter in order to collect more data. New instruments as Laser Precipitation monitoring system and Remote Scanner for ice-thickness measurements will be used.

In the future, this research will focus on the design and prototype assembling of an automatic station that will be installed close to some critical power line, in order to alert the grid operators during dangerous snowfall events. This system will be certainly essential to manage critical events by using both electricity dispatching solutions as de-icing or anti-icing techniques [17].

VII. Acknowledgments

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between ERSE and the Ministry of Economic Development - General Directorate for Energy and Mining Resources stipulated on June 21, 2007 in compliance with the Decree n.73 of June 18, 2007.

The authors would like to acknowledgments their colleagues Pietro Marcacci, Gilberto Mariani and Brigida Melga for the participation in experimental campaigns, and Dario Ronzio, Elena Collino, Giovanni Pirovano for the technical support.

VIII. References

[1] G. Flocchini, C. Palau, P. Nicolini and F. Tavano, "Icing on overhead lines: some results of research," *L'Energia Elettrica*, vol. LXII, fascicolo 11, 1985.

[2] M. Suzuki, K. Hsieh, M. Ono, "*A study of the calculation of terminal velocity of falling snowflakes"*, vol. 20. No.1, Jamagata Univ., Department of Electronic Engineering, Faculty of Engineering, Jan.1988.

[3] American Society of Civil Engineers, "*Minimum Design Loads for Buildings and Other Structures- Chapter C10 – Ice Loads-Atmospheric icing*" ; Reston, VA 20191 USA

[4] Wakahama G., Kuroiwa D., Goto D., - "*Snow accretion on electric wires and its prevention*." - J. Glaciol. 19, 479-487; 1977.

[5] S. M. Fikke, F. Downes, J-F. Drapeau, A.J. Eliasson, M. Ervik, M. Farzaneh, A.P. Goel, E.J. Goodwin, J. Hrabanek, J. Jakse, S. Krishnasamy, L. Makkonen, F. Popolansky, J. Ruhnau, C.C. Ryerson, Y. Sakamoto, V. Shkaptsov, J.B. Wareing "Guidelines for field measurement of ice loadings on overhead power line conductors," *Cigrè Task Force*, 22.06.01. Published by Cigrè.

[6] A. Leblond, S. Chereshnyuk, A.J. Eliasson, M. Farzaneh. S.M. Fikke, A. Haldar, C. Hardy, H. Hawes, M. Ishac, S. Krishnasamy, M. Le-Du, Y. Sakamoto, K. Savadjiev, V. Shkaptsov, N. Sudo, S. Turbin, B. Wareing – "Guidelines for meteorological icing models, statistical methods and topographical effects" – *CIGRE', Working Group B2.16, Task Force 03*, April 2006.

[7] Fikke S., Ronsten G., Heimo A., Kunz H., Ostrozlik M., Personn P.-E., Sabata J., Wareing B., Wichura B., Chum J., Laakso T., Santti K., Makkonen L. – "Atmospheric Icing on Structures Measurements and data collection on icing: State of Art" - *COST 727:*, Publication of Meteoswiss, 75, 110 pp, 2007.

[8] P. Bonelli and M. Lacavalla, "Trends in snow deposition on overhead electric lines: an example of using synoptic data to investigate the relation black-out risk / climate change", *NATO Workshop "Weather / Climate Risk Management for the Energy sector* " S. Maria di Leuca 6-10 October 2008.

[9] P. Admirat, Y. Sakamoto – 1988 - "Wet snow on overhead lines: state of art." *In Proc. 4th Int. Workshop on the Atmospheric Icing of Structures*, 7-8 September 1988, Paris (pp.7-10).

[10] P. Admirat, Y. Sakamoto, B. De Goncourt – 1988 – "Calibration of a snow accumulation model based on actual cases in Japan and France". *In Proc. 4th Int. Workshop on the Atmospheric Icing of Structures*, 7-8 September 1988, Paris(pp.129-133).

[11] K.J. Finstad, S.M. Fikke, M. Ervik. - "A comprehensive deterministic model for transmission line icing applied to laboratory and field observations."- *In Proc. 4th Int. Workshop on Atmospheric Icing of Structures*, pp. 227-231.

[12] P. Bonelli, M. Lacavalla "Meteorological events and power electric lines", *Terna - Rete Elettrica Nazionale*, Engineering Department. Roma, 2008.

[13] *IEC 61774* - Overhead lines meteorological data for assessing climatic loads - 14 August 1997.

[14] *UNI – Eurocode 1:* Basis of design and actions on structures – Part 2-3: Actions on structures – Snow loads – October 1996.

[15] Eliasson A.J. , Thorsteins E. , Olafsson H. – 2000 -"Study of wet snow events on the south coast of Iceland" - *9th International Workshop on. Atmospheric Icing of Structures - IWAIS 2000* , Chester, England, 5 – 8 June, 2000.

[16] Eliasson. Á.J., Thorsteins. E., "Field measurements of wet snow Icing accumulation" - *9h International Workshop on Atmospheric Icing of Structures - IWAIS 2000* , Chester, UK, 5 – 8 June, 2000.

[17] C. Volat, M. Farzaneh, – "De-icing/anti-icing techniques for power lines: current methods and future directions" – *IWAIS XI, Montreal,* June 2005.

[18] Y. Sakamoto – "Snow accretion on overhead wires" – *Philosophical Transactions of the Royal Society* (2000) 358, 2941-2970.

[19] G. Poots -"Introductory remarks" - *Philosophical Transactions of the Royal Society* (2000) 358, 2803-2810.

[20] L. Makkonen –"Models for the growth of rime, glaze, icicles and wet snow on structures" *Philosophical Transactions of the Royal Society* (2000) 358, 2913-2939.