THERMAL RISK ASSESSMENT ON OVERHEAD CONDUCTORS USING NUMERICAL WEATHER MODELING

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Abstract. *This work presents a new methodology to calculate the thermal risk assessment of overhead lines on a geographical area, using a numerical weather model. Therefore, it is possible to generate maps where zones of high or low thermal risk are identified so critical sags can be determined. These maps could improve the operation of power lines through safety practices and give support to review of NBR 5422 standard.*

Keywords*: Numerical weather model, downscaling, ampacity, thermal risk, power overhead lines.*

1. INTRODUCTION

The numerical weather model has been often used in engineering applications such as wind power assessment, weather forecast, hydrology and air pollution. In this work, the numerical model is used to optimize the capacity of power lines, which is strongly influenced by weather conditions. Therefore, it is possible to use a numerical weather model to create a virtual climatology of a geographical area, where the capacity of power lines can be analyzed.

Today, the SIN (National Interconnected System) has 93,868km of power lines installed in Brazil and it is operated by ONS (National Operator of Electrical System). The SIN's network extension has grown by 3.5% every year since 1999 and has an outlook to grow by 6% each year in the next three years (ONS, 2008). So, this development has encouraged Brazilian authorities to find new solutions to increase the capacity of power lines.

Recently, the Brazilian Government has reviewed the NBR 5422 standard (1985), which defines the guidelines for projects of overhead lines, in order to facilitate the operation of power lines trough the Resolution 191/05 (Aneel, 2005). The review describes a method to calculate the capacity limit on long-term period, which is based on Cigré (International Council on Large Electric Systems) (1992). Basically, it is considered the stabilities of the lines, the capacities of the equipments, the weather conditions and the conductor properties. However, the most important limiting factor is the safety factor, which is the distance of the cable to the ground and depends on conductor temperature.

Globally, conservative fixed values based on worst weather condition, or "deterministic method", have been used for line capacity. Although it is a safe practice, it causes in most of the time an underutilization of the line (Foss and Fernandez, 1983 and Morgan, 1986). In the meantime, statistical methods have been suggested (Menezes et al., 1985 and FT-Ampacidade, 1992) to increase the capacity of a line, though these methods are restricted only to sites where there is a long climatology record. Thus, the lack of consistent weather data in Brazil limits the use statistical method nowadays.

In order to overcome this situation, the numerical weather model ARPS (Advanced Regional Prediction System) by Xue et al. (2000) is used to interpolate reanalysis data from NCEP (Kalnay et al., 1996) creating a virtual climatology with high spatial and time resolution. Consequently, it is possible to use the statistical method in a spatial resolution to generate maps of thermal risk, which allow the identification of critical sags that limit power lines capacity.

The following methodology can be divided in four steps. Fist of all, it is described how the data is made. Second, an analysis of uncertain is taken by comparing simulated data against measured data from airports. Third, the temperature of the conductor is calculated by Cigré approach using the results of simulated data. Finally, it is processed the time series of conductor temperature to calculate the thermal risk for each grid. Finally, it is possible to create maps of thermal risk. The research domain is Southern Brazil and ten years period, from 1998 to 2007

2. METHODOLOGY

2.1. Numerical Weather Model

The weather data are obtained by the use of numerical weather model. As mention previously, it is used reanalysis data from NCEP (Kalnay et al., 1996) and the ARPS (Xue et al., 2000) to interpolate the reanalysis data, and then obtaining data of solar radiation, air temperature, wind speed and direction with high spatial and time resolution. This technique is called downscaling (Hewitson and Crane, 1996). The numerical weather model is a technique that uses computational technology to solve the differential equations that characterize the thermal-dynamic state of the atmosphere. This atmospheric model also considers the influence of the topography and its characteristics such as type of soil, lakes, ocean, cities and forests.

Starting from an "initial condition", the model can simulate and recreate weather data where there are no measurements. This "initial condition" (reanalysis from NCEP) is like a snapshot of the atmosphere where the variables used are interpolated at each grid point. The reanalysis are the best meteorological database existed today over the South America. It has a horizontal resolution of 200x200km and an interval of 6 hour rate. In addition, it is possible to use other data than reanalysis to improve the simulation.

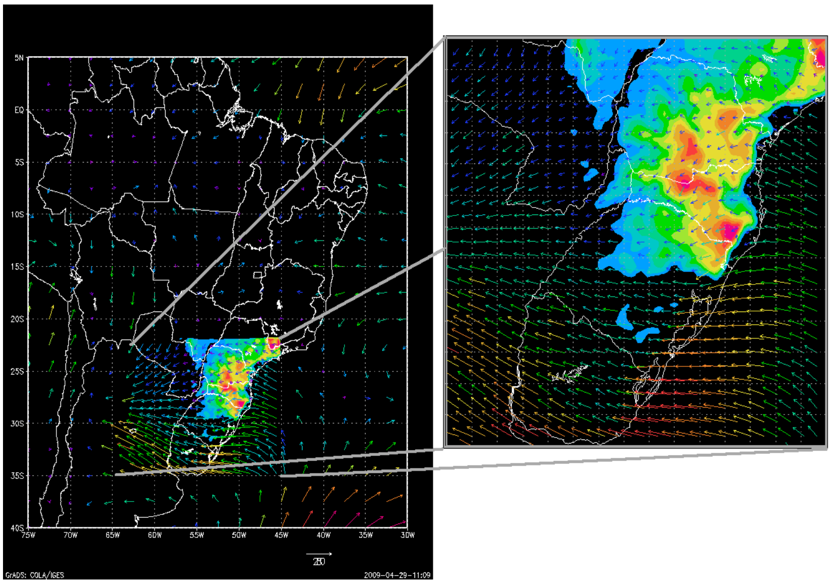


Fig. 1 Illustration of how the data is interpolated. Map of wind vector from NCEP (big picture), wind vector interpolated by downscaling technique (small picture) and shaded color is topography.

The best results of the simulation are taken from daily basis, so the model starts every day at 21 hours and it is integrated 27 hours, but the first three hours are skipped because the model is still adjusting to the initial condition. The boundary condition is updated with the reanalysis every 6 hours. Then the outcomes are grid maps of wind speed and velocity, air temperature and solar radiation with 123x143 grip points that means 10km horizontal resolution and 1 hour interval from 1998 to 2007.

2.2. Atmospheric Model - Uncertain of Analysis

The analysis of uncertain of ARPS model is taken by comparing the simulated data against observed data from the airports, called Metar. This data is obtained from NCDC (National Climatic Data Center) of the U.S. and it pass by a data quality control system (Lott, 2003). It is selected just eleven airports because only those sites have 70% of data validated for a period of 1998 to 2007. Even thought Metar has air temperature data, wind speed and direction it does not have solar radiation data and then the uncertain of the solar radiation can not be evaluated directly. As solar radiation is correlated with air temperature (Hargreaves et al., 1982) and it is not the most important variable of the equation (Balck and Rehberg, 1983), its uncertain is considered similar to the air temperature.

For the air temperature and wind, it is used the standard objective methods to analyze the uncertain of the variables (Wilks, 2006) such as Pearson conrrelation (R), mean error (ME), absoluty mean error (MAE), mean squared root error (RMSE) and the rate of its standard deviations (σsim/ σobs). In addition, it is also evaluated the conductor temperature error by calculating Cigré approach using Metar and simulated data. The results are showed in Table 2, Table 3 and Figure 4.

2.3. Thermal Equation of Overhead Conductor

The thermal equation of overhead conductor used in this work is the same equation and suggestion used by Cigré (1992), see Equation 1. This equation has been largely used by most international institutions (Cigré, 2006) and it is also the reference for the review of the NBR 5422 standard. The details of the equation are not presented here but are exactly the same of Cigre (1992).

$$Q_J + Q_S = P_c + P_r \tag{1}$$

where,

Q_J	Joule Heating	[W/m]
Q_S	Solar Radiation Heating	[W/m]
PC	Convective Cooling	[W/m]
PR	Radiative Cooling	[W/m]

It is considered a steady state of thermal equilibrium where all the heat transferred is instantaneous. The reason of this simplification is that the interval used is one hour, which is large enough (Black and Rehberg, 1985). Also, the current used is AC and then it is not required corrections from DC to AC currents.

The characteristics of the conductor are also essential to set all the calculations. The conductor used is an aluminum ACSR (Aluminum Conductor Steel Reinforced) Grosbeak type. The main characteristics of the conductor are listed below, Table 1.

Table 1. Characteristic of Grosbeak Conductor

Parameters	**Values**	**Units**
Size	636	[mcm]
External diameter	0.02516	[m]
Resistance at 20°C	8,85E-05	[ohms/m]
Resistance thermal coeficiente AC	0,00403	[ohms/°C]
Absortivity$^{(3)}$	0,78	[-]
Emissivity$^{(3)}$	0,77	[-]
Current operation (AC)	600	[A]
Temperature of the Projet	60	[°C]
Azimute of the line	0	[°]

$^{(3)}$ Values suggested by ONS (Varela, 2007).

After defining the properties of the conductor, temperatures of the conductor can be calculated for each grid point of the 123x143 matrix for Southern Brazil and for all 87,648 hours or ten years time series. Thus it totalizes 1.53 billion set of calculus.

2.4. Thermal Risk Assessment

The statistical tools used to calculate the thermal risk is the Probability Distribution Function, Equation 2, so it can determine the number of occurred events for a specific threshold of temperature, which in this case is 60°C. In order to process, it is required a time series of at least ten years for a reasonable statistical analysis (FT Ampacidade, 1992).

$$Thermal\_Risk = P(t \geq t_{ref}) = 1 - \sum_{t_{\min}}^{t_{ref}} n(t)/N \tag{2}$$

where,

N(t)	Number of events of temperature conductor t	[-]
N	Total number of eventss (87648)	[-]
t_{ref}	Reference temperature of the project	[°C]
t_{min}	Minimum Temperature of the conductor	[°C]
$P(t>t_{ref})$	Probability of t_{ref} or higher to be reached	[-]

For each grid point, a probability distribution function is produced and then the thermal risk can be determined. Figure 2 illustrates a probability distribution of the conductor temperature. After finding the probability, maps of thermal risk are drawn for Southern region of Brazil (Figure 5).

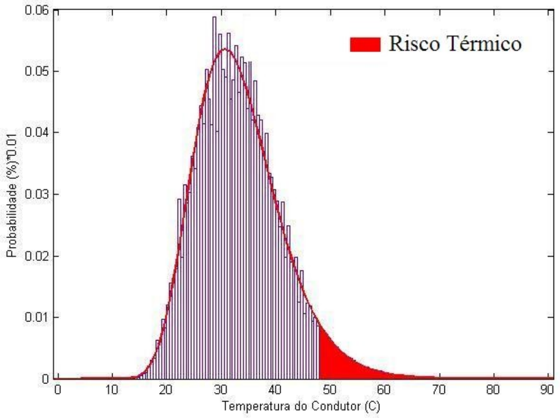


Figure 2. Histogram example of probability distribution of temperature conductor
And the curve adjusted by Log-Normal, at São Paulo city.

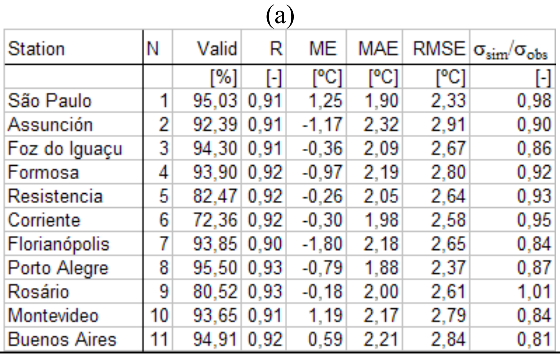
3. RESULTS

3.1. Uncertain analysis of ARPS model

An analysis of uncertain is made for air temperature, wind speed and wind direction, which is divided by zonal and meridional components. In Table 2, it is presented the uncertain of the ARPS model compared to observed airport data.

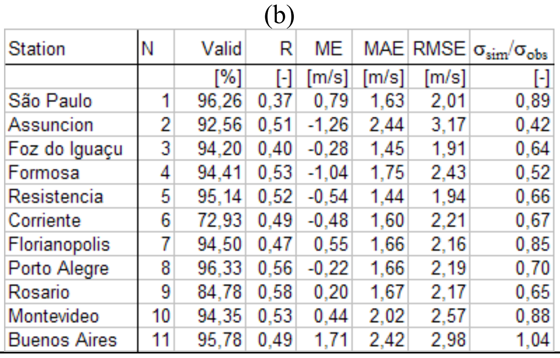
Table 2. Uncertain of meteorological variables: (a) Air temperature, (b) wind speed scalar,
(c)Zonal wind, (d) Meridional wind

(a)



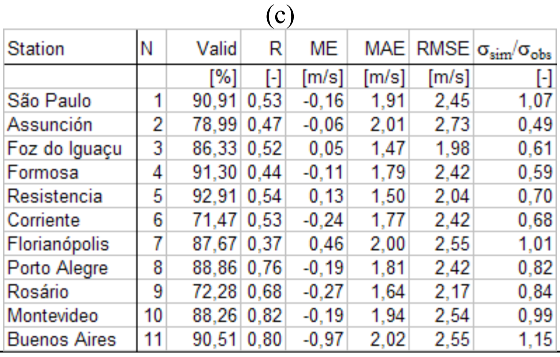
Station	N	Valid	R	ME	MAE	RMSE	$\sigma_{sim}/\sigma_{obs}$
		[%]	[-]	[°C]	[°C]	[°C]	[-]
São Paulo	1	95,03	0,91	1,25	1,90	2,33	0,98
Assuncíón	2	92,39	0,91	-1,17	2,32	2,91	0,90
Foz do Iguaçu	3	94,30	0,91	-0,36	2,09	2,67	0,86
Formosa	4	93,90	0,92	-0,97	2,19	2,80	0,92
Resistencia	5	82,47	0,92	-0,26	2,05	2,64	0,93
Corriente	6	72,36	0,92	-0,30	1,98	2,58	0,95
Florianópolis	7	93,85	0,90	-1,80	2,18	2,65	0,84
Porto Alegre	8	95,50	0,93	-0,79	1,88	2,37	0,87
Rosário	9	80,52	0,93	-0,18	2,00	2,61	1,01
Montevideo	10	93,65	0,91	1,19	2,17	2,79	0,84
Buenos Aires	11	94,91	0,92	0,59	2,21	2,84	0,81

(b)



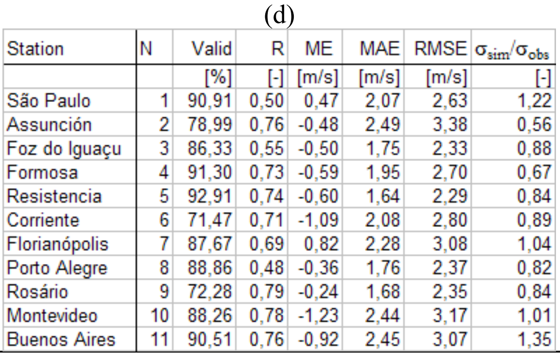
Station	N	Valid	R	ME	MAE	RMSE	$\sigma_{sim}/\sigma_{obs}$
		[%]	[-]	[m/s]	[m/s]	[m/s]	[-]
São Paulo	1	96,26	0,37	0,79	1,63	2,01	0,89
Assuncion	2	92,56	0,51	-1,26	2,44	3,17	0,42
Foz do Iguaçu	3	94,20	0,40	-0,28	1,45	1,91	0,64
Formosa	4	94,41	0,53	-1,04	1,75	2,43	0,52
Resistencia	5	95,14	0,52	-0,54	1,44	1,94	0,66
Corriente	6	72,93	0,49	-0,48	1,60	2,21	0,67
Florianopolis	7	94,50	0,47	0,55	1,66	2,16	0,85
Porto Alegre	8	96,33	0,56	-0,22	1,66	2,19	0,70
Rosario	9	84,78	0,58	0,20	1,67	2,17	0,65
Montevideo	10	94,35	0,53	0,44	2,02	2,57	0,88
Buenos Aires	11	95,78	0,49	1,71	2,42	2,98	1,04

(c)



Station	N	Valid	R	ME	MAE	RMSE	$\sigma_{sim}/\sigma_{obs}$
		[%]	[-]	[m/s]	[m/s]	[m/s]	[-]
São Paulo	1	90,91	0,53	-0,16	1,91	2,45	1,07
Assuncíón	2	78,99	0,47	-0,06	2,01	2,73	0,49
Foz do Iguaçu	3	86,33	0,52	0,05	1,47	1,98	0,61
Formosa	4	91,30	0,44	-0,11	1,79	2,42	0,59
Resistencia	5	92,91	0,54	0,13	1,50	2,04	0,70
Corriente	6	71,47	0,53	-0,24	1,77	2,42	0,68
Florianópolis	7	87,67	0,37	0,46	2,00	2,55	1,01
Porto Alegre	8	88,86	0,76	-0,19	1,81	2,42	0,82
Rosário	9	72,28	0,68	-0,27	1,64	2,17	0,84
Montevideo	10	88,26	0,82	-0,19	1,94	2,54	0,99
Buenos Aires	11	90,51	0,80	-0,97	2,02	2,55	1,15

(d)



Station	N	Valid	R	ME	MAE	RMSE	$\sigma_{sim}/\sigma_{obs}$
		[%]	[-]	[m/s]	[m/s]	[m/s]	[-]
São Paulo	1	90,91	0,50	0,47	2,07	2,63	1,22
Assuncíón	2	78,99	0,76	-0,48	2,49	3,38	0,56
Foz do Iguaçu	3	86,33	0,55	-0,50	1,75	2,33	0,88
Formosa	4	91,30	0,73	-0,59	1,95	2,70	0,67
Resistencia	5	92,91	0,74	-0,60	1,64	2,29	0,84
Corriente	6	71,47	0,71	-1,09	2,08	2,80	0,89
Florianópolis	7	87,67	0,69	0,82	2,28	3,08	1,04
Porto Alegre	8	88,86	0,48	-0,36	1,76	2,37	0,82
Rosário	9	72,28	0,79	-0,24	1,68	2,35	0,84
Montevideo	10	88,26	0,78	-1,23	2,44	3,17	1,01
Buenos Aires	11	90,51	0,76	-0,92	2,45	3,07	1,35

For a period from 1998 to 2007, only eleven stations of 174 official Metar and Sinop sites present consistent data over 70% in all region domains (Figure 3a e 3b). In fact, it is not new that the lack of good meteorological data in Brazil and South America is huge. Therefore, without the technique of downscaling, the statistical method is practically impossible to use and deterministic method has to be considered again.

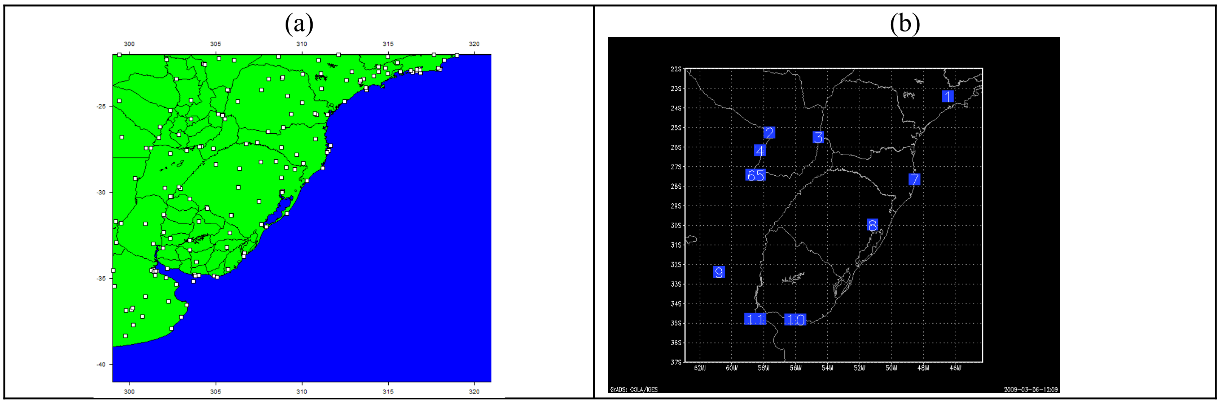


Figura 3. (a) Metar (airport) and Sinop (WMO) network of weather stations,
(b) Weather stations selected for data available over 70%.

The best results of correlation (R) are for air temperature, presenting values around 0.9, and the worst correlation is for wind speed, presenting values around 0.5. The zonal and meridional winds are not homogeneous for each site because of particular topography.

The means errors, or “bias”, are negative in most of the sites to air temperature. On the other hand, the wind has an undefined bias if compared to observed data from airports. The RMSE are satisfactory for air temperature with values less than 2.91ºC, and wind speed with values no greater than 3.17m/s. The ratio of standard deviation for temperature is closed to one, and therefore this is a good skill of the model. The wind speed shows a ration around 0.7, that means the model under estimate the behavior of the atmosphere by 30%. It is significantly lower because the model can not simulate gust winds.

Also, an evaluation of conductor temperature is made by comparison of the one calculated by Cigre approach, using simulated data, and against airport meteorological data (Table 3). It is observed that the means, maximum, minimum and standard deviations simulated by ARPS are very similar to the observed meteorological data from airports. Errors are estimated as mentioned at item 2.2 and ploted on the map (Figure 4).

Table 3. Uncertain of conductor’s temperature

Station	N	Avg_ob	Avg_sim	Max_ob	Max_sim	Min_ob	Min_sim	σ_{obs}	σ_{sim}
		[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
São Paulo	1	33,3	30,0	80,7	79,1	7,5	9,0	7,9	7,6
Assuncion	2	35,3	35,9	80,2	85,0	7,1	11,5	8,6	8,8
Foz do Iguaçu	3	36,5	37,0	77,9	80,8	5,2	11,8	9,4	8,9
Formosa	4	35,2	35,4	81,8	87,5	5,3	10,6	8,9	8,6
Resistencia	5	34,4	34,8	92,2	83,6	5,2	9,1	9,2	8,8
Corriente	6	33,2	33,2	90,2	84,7	7,5	8,8	8,9	8,7
Florianopolis	7	34,6	30,8	83,5	71,8	4,7	9,0	7,2	6,4
Porto Alegre	8	31,9	31,4	85,5	83,3	6,6	8,1	8,3	9,2
Rosario	9	30,4	29,5	77,6	79,9	2,0	5,5	9,2	9,2
Montevideo	10	25,1	26,3	74,1	82,0	5,0	5,9	7,2	7,8
Buenos Aires	11	28,6	26,4	81,1	84,8	3,5	6,3	9,0	8,4

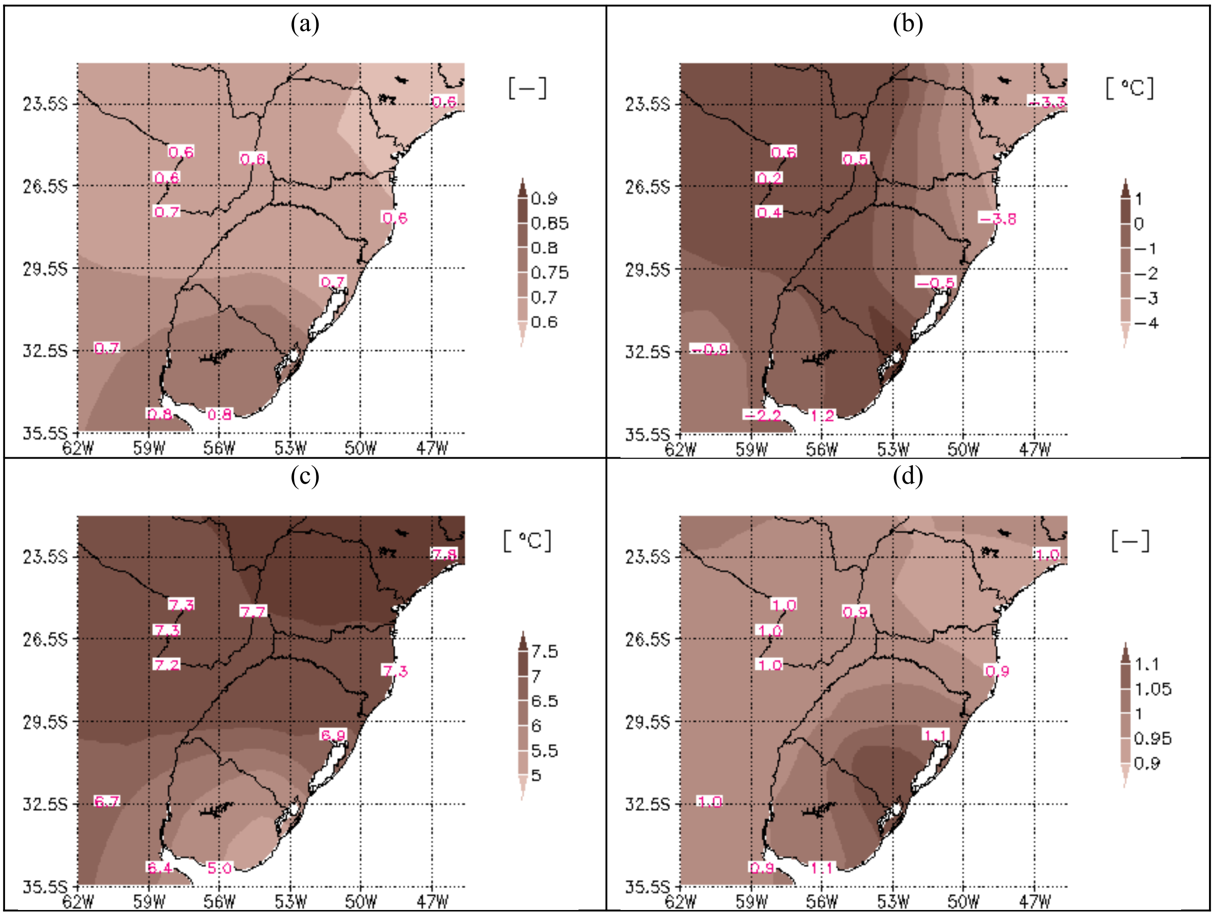


Figure 4. Uncertain of Conductor’s Temperature (ºC) Simulated vs. Observed:
(a) Pearson Correlation (R), (b) Mean Error (bias) Simulated-Observed,
(c) RMSE – Root Mean Squared Error, (d) Ration Sigma Simulated/Sigma Observed.

Finally, it shows that the ARPS model when used together with Cigre approach can make a very good simulation, with spatial correlation of 0.7 (Figure 4a) and a ratio of standard deviation close to 1 (Figura 4d). The correlation in São Paulo and Florianópolis are lower and their bias are significant large because one is strongly influenced by metropolitan region and other is an island, respectively, and the model could be erroneously characterizing the island as part of the ocean. The RMSE, at Figure 4c, are lower than 7.8 ºC, which means the wind and its turbulent behavior have a strong influence on temperature conductor error (Table 2b).

It can concluded that the weather model is satisfactory compared with the temperature of conductor calculated by meteorological data from the airports. In addition, Cigre approach (Item 2.3) is conservative for low winds (Mizuno et al., 2001 and Gabaglia, 2005). Therefore, the maps developed in this work are conservative and the errors are limited mostly by the error of the wind speed and direction.

3.2. Thermal Risk Map

The thermal risk map (Figure 5), as temperature project fixed at 60 ºC, shows a time percentage that the conductor reaches temperatures above 60 ºC. All power lines are considered as fixed orientation of north-south direction. The emissivity of the conductor is 0.77, the absortivity is 0.78 and current is 600 A for all transmission lines.

The major part of Southern Brazil presents a low risk up to 4%. Mountain regions show more favorable conditions because of the lower temperatures and stronger winds. In the other hand, valleys are identified as high thermal risk regions as shows at Figure 5. A particular case is found located at Itaipu hydroeletric power plant, where the influence of the dam is notable on the map. The lake created by Itaupu’s dam cooled the microclimate surround the lake because of lake’s breeze and lower average temperatures surround (Stivari et al., 2003). The impacts of the lake are also eminent after the river pass the dam where the highest thermal risks are identified with values up to 7%.

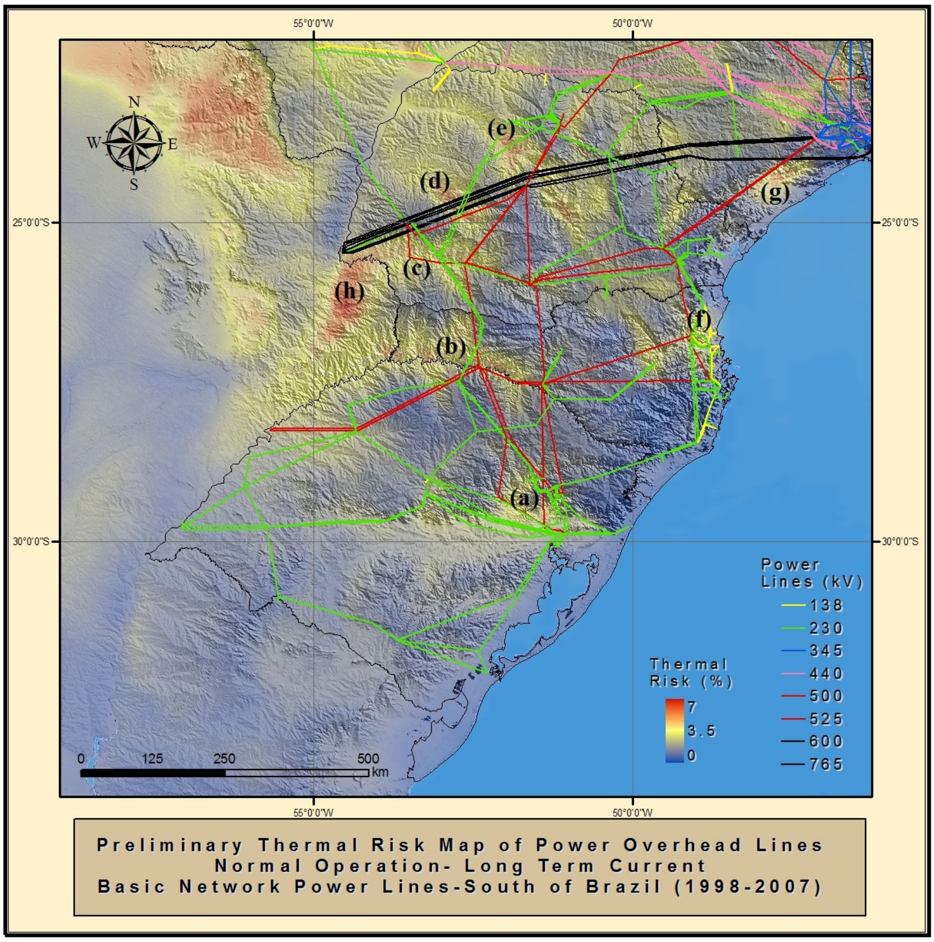


Figure 5. Preliminary Thermal Risk Map of overhead conductor and the topography shaded.
(a) Taquari River Valley (RS), (b) Uruguai River Valley (SC), (c) Iguaçu River Valley (PR),
(d) Piquiri River Valley (PR), (e) Ivaí River Valley (PR) and Tibagi River Valley (PR),
(f) Itajaí Valley (SC), (h) Ribeira Valley (SP), (h) Itaipu's Hidro Power.

The map of thermal risk in Figure 5 is also overlayed with SIN's power lines network. Some limitations of this map are: the orientation of the lines, types of conductors, current, absortivitiy and emissivity of the cable that are all considered as fixed values. Thus, this map is specific and depends on the properties as described in item 2.3. To make the right decisions, it is recommend simulating other different kinds of properties such as different line orientation, types of conductors and current. So, combining different maps is possible to have a complete evaluation of the thermal risk for each specific power line.

4. CONCLUSION

This work presents a new methodology that allows making an assessment of the thermal risk using numerical model. The resolution of 10x10km is satisfactory for a mesoscale analysis, but it is required a microanalysis and a monitoring sitting *in loco* for a 100% safety practice. The uncertain analysis is limited by few weather stations and a large number of weather stations is essential for a better evaluation of the model.

The most important result of this work is the map that can identify the critical sags along the lines and, based on this information, it is possible to define the best route for the new line or reduce the costs of maintenance by monitoring only regions that have high risks.

5. ACKNOWLEDGEMENTS

This work, developed at the Laboratory of Engineering Conversion Process and Energy Techninology (LEPTEN) is part of RMLT project (Weather station on power transmission lines for monitoring environmental condition), funded by the Financial Company for Research and Projects (FINEP). The authors are thankful for the cooperation of the National Agency of Power Electric (ANEEL), National Operation of Electrical System (ONS) and the Departament of Mechanical Engineering (EMC) of the Federal University of Santa Catarina State (UFSC).

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