THE UNIVERSITY OF MANITOBA

MEASUREMENT AND MODELLING OF RADIO NOISE FROM ELECTRIC POWER LINES IN THE RURAL REGION SURROUNDING THE CITY OF WINNIPEG.

BY

MOHAMED TAREK GAD

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ABSTRACT

The noise characteristics of transmission lines in the high frequency bands extending to 32 MHz are experimentally investigated. The noise emitted from transmission lines affecting radio reception is analysed with the use of a linear regression technique to model the various classes of power lines classified according to line voltage.

These models provide a tool to predict the performance of radio reception in the presence of power line interference. It was observed that noise levels were affected by the line voltage and the load conditions on the line.

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Chapter I

INTRODUCTION

In the last two decades, the increasing need for transmission of large amounts of electrical energy over the long distances which separate generating stations from consumption centers, has resulted in the development and installation of transmission lines operating at very high voltages. At the same time, concern is also increasing regarding the environmental effects of such lines. One of these environmental factors is the radio interference (RI) generated by electromagnetic sources originating from the transmission lines. Generally, there are two sources of electromagnetic interference (EMI) associated with power lines. One of these is due to high voltage corona, the other is the result of gap discharge or microsparks [1].

The amount of electromagnetic interference generated by a power line is controlled to a large degree by the conductor radius and phase spacing. Choice of conductor radius and of phase spacing has a direct bearing upon the corona performance of the line [2]. The susceptibility of a line to the occurrence of gap discharges may also be related to conductor radius and phase spacing as well as to insulator type.

There are other factors which affect the electromagnetic performance of the line which cannot be eliminated by design. Weather conditions and the topology of the locale in which the line is erected constitute the two most important aspects over which the designer has little control.

The phenomenon of corona discharge is normally caused by small protrusions on the line conductors and by conductor surface contaminants such as water droplets, dirt and other material. The electric field at the protrusions is enhanced and produces corona at normal operating line voltages [3,4]. Corona is a faint glow that may be observed in the electrically overstressed air surrounding a power line component. The electric field intensity changes from space point to space point and is especially high adjacent to sharply curved surfaces such as those of protrusions. Upon raising the voltage of such surfaces, a critical level of the electric field may be exceeded and the physical processes causing corona will be initiated. When this happens, it is said that the corona onset level has been reached. A further increase in the applied voltage will result in an enhancement of the corona activity.

Design values of voltage gradients refer to smooth (non-stranded) conductors with clean surfaces and these values assume normal dielectric strength of air. In reality, conductors are stranded and they, along with other hardware, can become contaminated. Stranding and contamination constitute surface irregularities which cause local concentration of the electric field. As soon as this concentration exceeds the critical value of the voltage gradient (corona onset value), corona discharges will occur.

In addition to these processes, corona is also influenced (even more strongly) by weather effects. Corona onset voltage (for any given geometry) is determined by air density and humidity [5-7] . Corona voltage varies inversely with air density. Thus, it varies directly with air pressure and inversely with temperature [7]. When rain drops, ice or snow accumulate on conductors and on hardware surfaces, they also cause irregularities which increase the surface voltage gradient.

Corona discharge is accompanied by a variety of manifestations, such as chemical effects, primarily those of ionization of air components. Accoustical waves are also formed, as a consequence of molecular collisions and from avalanche formations during the discharge process. Also, there is electromagnetic radiation that accompanies the pulsative forms of discharges. Generally, all of the above constitute an energy loss, however, corona loss is not the only phenomenon that accompanies the occurrence of corona. Interference with communication facilities is the consequence of the electromagnetic radiation. This radiation, as well as corona loss, must be limited to an acceptable value as, otherwise, such a vital service as radio reception could be jeopardized.

The gap type sources of electromagnetic radiation can occur in insulators, at tie wires, between hardware parts, at small gaps between neutral or ground wires and hardware, and in electrical equipment that is defective, damaged or improperly designed or installed. Gap-type sources can and do occur frequently on overhead power lines; however, these can be found and eliminated when necessary. The gap type sources are produced by two electrically isolated surfaces charged by the action of an alternating electric field. When the potential difference between them increases until the dielectric withstand-strength of air is exceeded, the air in the gap breaks down. During the break down phase, charge is carried from one surface to the other, until their potentials are equalized and the arc is extinguished. The insulating strength of air is then re-established and the stage is set for the new charging process and for repetition of the breakdown [6]. The influence of weather conditions upon gap sources is found to be opposite of that upon corona activity. Water droplets of rain short out the minute gaps and thus prevent the discharge process.

EMI has a greater affect on the quality of radio reception in certain frequency ranges than in others. Reception in the AM broadcast frequency range is more susceptable to the presence of corona generated RI, than reception in other broadcast ranges. Electric power lines provide a natural path for EMI from the source to the receiver. This propagation mechanism is particularly important for the frequency range below about 30MHz, as the wave length is long in comparison with phase spacing[1].

Radio waves propagate through space in a number of modes termed as ground waves, sky waves and space or tropospheric waves. For broadcast and at lower frequencies, the propagation of radio signals is mainly accomplished by ground waves which are insensitive to weather conditions. However, these waves may be disturbed by natural electric discharges such as lightning which may increase the noise level significantly.

The quality of radio reception is a function of the signal to noise ratio, S/N, available to the receiver [8,9]. S/N is defined as the ratio of the average signal power to the average noise power in a given bandwidth. By reducing the noise level at the receiver input, the quality of reception improves.

The EMI emitted from power lines has been studied by others in order to determine the level of noise and its effect on radio, TV and communication services.

Lauber and Bertrand [10] measured the RI due to corona discharge from transmission lines over a seventeen day period in November 1976 at four sites in downtown Ottawa. They used a Singer electromagnetic interference meter, model NM37/57, along with a discone antenna and made measurements over a frequency range of 100-1000 MHz. This project was an extension of previous studies [11,12,13] on high frequency radio noise interference.

They obtained the antenna effective noise factor, F_a, and the voltage deviation, V_d (which will be defined in chapter two) for a discone antenna. In the frequency range used, an antenna of this type has greater gain than the vertical monopole antenna used in radio environment studies.

In his study Lauber [13] made an amplitude probability distribution (APD) measurement of the noise spectrum in the high frequency bands emitted from the 775 KV project at Apple Grove. He used a monopole antenna with a Singer noise interference meter, model NM26T, to carry out the measurements. He has shown that values for the noise parameters usually measured by radio interference meters, except for the quasi-peak parameter, could be obtained from the APD data. He concluded that the APD of the noise can be deduced from the measured root-mean-square noise voltage and its voltage deviation. He also showed that the inverse of this is true, that is to say, by measuring these two parameters one can predict the APD of the noise which is a measure of the performance of radio reception in the presence of transmission line EMI.

Herak and Kirk [14], in a project of the Department of Communication, studied transmission line noise in the city of Winnipeg during the summer of 1977. They were concerned with power line noise in the urban area and took measurements of the root-mean-square voltage (V_{rms}), the quasi-peak voltage (QP) and the field intensity voltage (FI) of the noise spectrum. They used a modified Singer NM25T (equivalent to an NM26T) meter for the frequency range of 185 KHz-30MHz and a Singer NM37/57 meter for higher frequency bands up to 950 MHz. They measured F_a fifty feet away from the outer conductor of the power line and applied linear regression to several samples of F_a in order to obtain the noise prediction at that distance. For the lines they surveyed, they concluded that, at about 1 MHz, the S/N ratio of radio reception ranges from 25 to 29 dB, adequate for class B reception. Their measurement procedure will be discussed in another part of this thesis.

This study, as a part of the central Canada region study on Radio Interference from electric power lines by E.Bridges, W.R.Goddard, T.Gad and W.M.Boerner. [15], [16], investigates the properties of electromagnetic noise associated with power lines in the rural region surrounding the City of Winnipeg. Measurements of this noise were performed in order to determine the dependance of EMI on such parameters as frequency, lateral profile, line voltage and weather conditions. Fourteen test sites were selected on the Manitoba Hydro system. These sites were chosen such that interference from other sources (neighbouring power lines, commercial radio stations) was minimal. Accessability during poor weather conditions was also a factor influencing site selection. The AC transmission lines ranged in line voltage from 12 to 230 KV. One HVDC site on a 450 KV line was also chosen. An average of ten visits were made at each site over a one year period. Weather information and line operating conditions at each visit were obtained by mobile telephone.

Measurements of rms noise voltage across 50 ohms, V_{rms} and the voltage deviation, V_d , were made using a Singer NM26T meter (which has a noise bandwidth of 3.36 KHz), coupled through a matching network, to a Singer 9 foot long monopole rod antenna. Nine test frequencies in the range from 0.3 to 32 MHz were selected. Reading were taken at each of the selected frequencies at a location 50 feet perpendicular from the power line. At certain sites that produced significant noise levels a lateral profile was obtained by moving the measurement station (a van) to several locations extending out to 500 feet from the center of the line. The data obtained were entered into computer files.

Since power line noise is a random phenomenon, only a statistical analysis of its characteristics will yield meaningful results [19]. In this study, computer programs were developed to perform this analysis on the collected data base of the voltage deviation, V_d, and for the effective antenna noise factor, F_a, calculation. The linear regression technique [17]-[19] is applied to construct prediction models for the various classes of power lines, classified according to line voltage. The models are obtained from data collected during the two major seasons, thus they describe noise emission in different weather conditions.

These models can be used to predict the noise levels from any one of the different classes of transmission lines erected in the same environment as that surveyed. According to these models, the performance of radio systems operating in a power line environment can also be predicted.

The second chapter presents the theoretical background necessary for obtaining the various noise parameters used. The noise parameter definitions are according to the international radio consultative committee, C.C.I.R., Doc. 322 [20]. In chapter three, the measurement plan, the instrumentation and the measurement procedure, along with the site selection process, are presented. Chapter four describes the methods used to process the collected data base for F_a and V_d, the computer programs prepared to analyse the data and the results of this study. The applications of the models to radio reception are also presented in chapter four. Chapter five introduces the summary and conclusions of this study.

Chapter II

DEFINITIONS AND THEORY OF ELECTROMAGNETIC INTERFERENCE PREDICTION PARAMETERS

2.1 INTRODUCTION

In this chapter, the parameters most generally used to predict power line noise emission are defined and explained. The definitions of other measurement factors applicable to this study are also presented.

Generally, it is agreed that no single noise parameter can satisfactorly characterize Radio Interference [20]. However, one parameter which is universally used to compare noise produced from different sources and which is easily related to most of the other parameters used, is the effective antenna noise factor F_a [20]. The definition and relationship of F_a to the measured root mean square noise voltage, V_{rms}, is given in this chapter. Also defined is the voltage deviation V_d, another important parameter used, along with V_{rms}, to obtain the amplitude probability distribution (APD) of the noise spectrum.

The electromagnetic emission from power lines is a random phenomenon thus, only a statistical analysis of this phenomenon produces meaningful results [13]. The regression model is a useful technique to estimate the values of this noise emission. Using the regression model, one can predict the levels of the noise emitted from a particular power line and the performance of radio reception in the presence of the particular power line.

2.2 THE EFFECTIVE ANTENNA NOISE FACTOR

The antenna noise factor, f_a, is defined as the ratio of the noise power available from a lossless equivalent antenna to a reference thermal noise power.

Thus:

$$f_a = \frac{P}{kTB} \qquad (1)$$

where

P is the mean noise power available from an equivalent lossless antenna (watts),

k is Boltzman's constant (1.38×10^{-23} Joules/K),

T is the reference temperature (Kelvin), $288^{\circ}K$,

B is the effective receiver noise bandwidth (Hz).

From equation (1), it is seen that $f_a$is a dimensionless factor, alternatively, one may define the quantity

$$F_a\,(dB) = 10 \log f_a$$

which is the noise power per unit bandwidth in dB relative to kT. Equation (1) can be written as:

$$F_a(dB) = P(dBW) - B(dBHz) + 204 . \qquad (3)$$

The power density received by a lossless antenna is given by:

$$p = \frac{E^2}{\eta} \qquad (4)$$

where

E is the electric field strength (V/m),

η is the free space impedance (ohms).

The electric field strength is given in terms of the effective antenna height H, by:

$$E = \frac{V}{2H} \qquad (5)$$

where V is the voltage induced at the antenna terminals. Substituting from (5) into (4) gives the power density :

$$p = \frac{V^2}{4H^2} \frac{1}{\eta} . \qquad (6)$$

The power received by the antenna P is equal to the power density of the lossless antenna multiplied by the effective antenna aperture A which is given by:

$$A = \frac{\lambda^2 D}{4\pi} \quad . \tag{7}$$

Thus:

$$P = p \; A \tag{8}$$

where

λ is the wave length of the received noise,

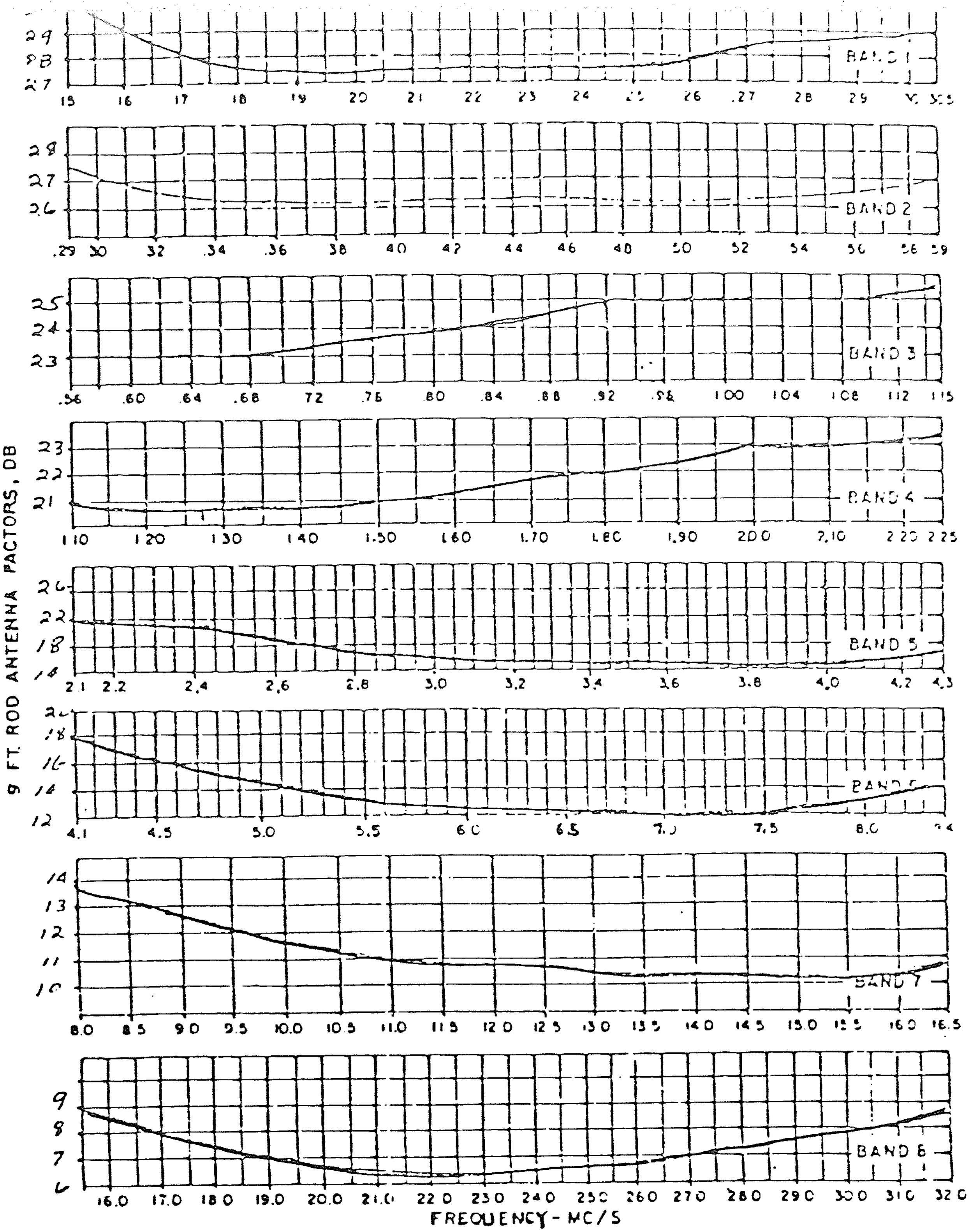
D is the antenna directivity.

Substituting equation (6) and (7) into (8) gives:

$$P = \frac{D}{4H^2} V^2 \quad \frac{\lambda^2}{480 \pi^2} \tag{9}$$

The term (10 log $\frac{D}{4H^2}$) is defined as the antenna factor and usually, for a given antenna, a graph of the antenna factors (AF) versus frequency is available with the manual of that particular antenna. For the monopole rod antenna which is used in this study, the antenna factors are given in Figure 1.

Equation (9) can be rewritten as:



CALIBRATED BY: ____________________ 93049-1 ROD ANTENNA

DATE: ______________ SERIAL NO. SAMPLE ONLY

Note: **Subtract 2 dB to obtain field strength antenna factor.**

Copied from Single 9 foot rod antenna manual

Figure (1)

Antenna factors for the nine foot long rod antenna.

$$P\ (dBW) = V(dBuV) + AF - 20\ \log f - 107.2 \qquad (10)$$

Substituting (10) into (3), we get:

$$F_a = V(dBuV) - 20\ \log f(MHz) - B(dBHz) + AF + 96.8. \qquad (11)$$

As seen from equation (11), F_a is obtained as a function of the measured noise voltage and the frequency for a given noise bandwidth.

2.3 THE VOLTAGE DEVIATION

The voltage deviation is defined as the dB difference between the rms and average noise envelope voltages. The voltage deviation, V_d, is used to identify the different types of noise amplitude distributions. Table 1 shows the classification of noise according to V_d as defined in C.C.I.R. Doc. 322 [20]. The voltage deviation is given by the equation:

$$V_d\ (dB) = 10\ \log\ (V_{rms})^2 - 20\ \log\ (V_{average}) \quad . \qquad (12)$$

2.4 SET NOISE

The term set noise is given to the internal noise of the detector meter. If the level of the power line noise to be detected is lower than that of the set noise, the detector meter will display the set noise. In other words near or below the level of set noise, power line noise cannot be detected. The set noise is obtained with respect to a reference temperature and is defined as:

$$f_s = \frac{T_e}{T_R} \qquad (13)$$

where

T_e is the effective temperature of the detector meter,

T_R is the reference temperature (288° K).

$$T_e = (f - 1)\ T_R$$

where f is the noise figure of the detector meter (11.7 dB for the NM 26T).

V_d (dB)	Type of noise distribution
1.05	Rayleigh
1.1	Gaussian
1.1 to 20	Impulsive

Table (1)

Classification of noise according to the voltage deviation, V_d

Thus,

$$F_s \text{ (dB)} = 10 \log (f - 1) T_R - 10 \log T_R \quad (14)$$

$$F_s \text{ (dB)} = 10.8 .$$

2.5 LINEAR REGRESSION AND MODELLING CONCEPTS

Investigators in numerous countries have previously studied the problem of radio interference as a determinestic problem. Their objectives were to establish relationships for radio noise levels in terms of the dimensions of the lines [9]. The formulas they used do not entirely explain the difference between the measured noise from different lines, nor the fluctuations in level which have been obtained from a given line in the course of time. In fact, it is observed that the noise level of a line is unstable and sensitive to the surface state of the conductors [4, 9]. Furthermore, noise levels can and do vary from one visit to the other, even when the line parameters (current,voltage and power) are the same. Therefore we regard the process that produces the noise as a random process.Accordingly, radio noise can only be defined in statistical terms [20].

Power line noise is a slowly varying random process, thus predicting its value with respect to independant parameters such as frequency, lateral distance and line voltage, can be treated as if it were a statistically determinable phenomena.

Generally, if a dependent variable Y changes with a change in an independent variable X, one should be able to predict Y from X. The method with which these predictions are made, are introduced in this section. Statistical terms that are involved in the discussion are also presented.

2.5.1 The linear regression equation

In order to obtain the linear equation of the form:

$$Y = a + bx \tag{15}$$

which gives a best fit to the scatter diagram of N data points, we must determine the coefficients a and b in such a way that the data points lie as close to the line as possible [15]. The method of least squares fit is the one most used in statistics. When applying this method a line is fitted thorough the data points in such a way that the squared error between the data point and the fitted one has its smallest possible value as shown in Appendix A. The corresponding a and b coefficients are obtained in the Appendix and are found to be :

$$b = \frac{\Sigma XY - \frac{\Sigma X \, \Sigma Y}{N}}{\Sigma X^2 - \frac{(\Sigma X)^2}{N}} = \frac{\Sigma XY - N\bar{X}\bar{Y}}{\Sigma X^2 - N(\bar{X})^2} , \qquad (16)$$

$$a = \bar{Y} - b\bar{X} \quad . \qquad (17)$$

Where

ΣX is the summation of the dependant variable,

ΣY is the summation of the independant variable,

$\bar{X}$ is the mean of the dependant variable,

$\bar{Y}$ is the mean of the independant variable.

The linear regression model is constructed with the knowledge of the slope, represented by b, and the intersection with the Y axis given by the constant coefficient a.

2.5.2 <u>The standard error of estimate</u>

The quantity that measures the spread of the data points around the fitted line of regression is defined as the standard error of estimate. It is a measure of how well the line of regression fits the data points. The smaller the standard error, the better the regression model fits the points. The standard error is given by the equation:

$$\hat{S}_e = \sqrt{\frac{\Sigma(Y_i - Y)^2}{N}} \quad . \qquad (18)$$

2.5.3 The standard deviation

The spread of data points around their mean is defined as the standard deviation and is given by the equation:

$$\sigma = \sqrt{\overline{Y^2} - (\bar{Y})^2} \quad . \qquad (19)$$

2.5.4 The correlation coefficient

The correlation coefficient, r, gives an assessment of the degree to which the line of regression fits the data points [15]. The formula for r is quite simple and is obtained by multiplying the deviations in X and Y (from their means) for all points and dividing the result by the standard deviation of X and that of Y multiplied by the total number of data points. The correlation coefficient is given by:

$$r = \frac{\Sigma(X-\bar{X})\ (Y-\bar{Y})}{N\ \sigma_X\ \sigma_Y} \qquad (20)$$

or

$$r = \frac{\frac{\Sigma XY}{N} - \bar{X}\bar{Y}}{\sigma_X\ \sigma_Y} \quad .$$

The deduction of this equation from the definition is presented in Appendix A. The closer the correlation coefficient is to unity, the better the line of regression fits the data points.

2.5.5 Confidence limits

From the sets of data under study, we try to ascertain the value of the unknown parameter (F_a), that is, to estimate its value. In doing this, it is desirable to have confidence that the value obtained represents that parameter. The limits within which the parameter has 95% probability of existence are called the 95% confidence limits. These limits define an interval which contains the mean of the parameter. Accordingly, one would have an estimate of the unknown parameter within this interval.

The concept of linear regression is applied to the data base collected for V_d and F_a to obtain the desired models of the electromagnetic interference from power lines as shown in chapter four.

Chapter III

MEASUREMENT

3.1 MEASUREMENT PLANNING AND SITE SELECTION

Studies previously performed [10]-[14] and the central Canada region study [15], [16] used certain technical considerations with regard to measurement planning and site selection. These considerations are reviewed in this chapter and appropriate criteria are accordingly assigned and presented.

The purpose of measurements and analysis is to characterize the electromagnetic noise from power lines with typical operating voltages, loads and in the environment of various weather conditions. The characterization of such noise sources is well established when the power lines chosen are isolated from other sources of interference. In order to construct a statistical model that is useful for predicting noise from similar lines, several lines that have the same line voltage should be available. To observe changes with weather, load and voltage parameters, several visits should be made to the lines.

The site selection criteria are based on the above, keeping in mind that sites to be selected should be free from other sources of interference, the following criteria were developed:

1) Lines should be at least one mile (preferably three miles) from other power lines.
2) The line should be at least three miles (preferably five miles) from the distribution or generating station.
3) Two to three lines of the same voltage should be available.
4) The lines should be accessible under most weather conditions and reasonably close to Winnipeg to allow several sites to be visited on each field trip.
5) To characterize the change of noise with distance from the center of the line, we must be able to make physical profiles on a path perpendicular to the line.
6) To obtain the line voltage and load data at the time of measurements, we need lines that are monitored by Manitoba Hydro.

In the measurement of EMI radiated by power lines, it is worth recalling that a radiating source produces a near field and a far field [1]. The main difference between these two fields is their amplitude reduction with distance from the source. The near field strength decreases as the square of the distance, while the far field reduction is directly proportional to the distance. The contribution of the near field is especially significant within distances that are shorter than one wavelength of the considered frequency, while the far field dominates at considerably longer distances. In order to characterize the electromagnetic interference radiated by power lines, it is important to examine its variation with distance in both the near and far fields. The frequency at which the noise is to be detected determines the boundary between these two fields. For the range of frequencies in which the noise was detected, the wavelength of noise ranged from 31.25 to 2916.66 feet corresponding to 32 and 0.343 MHz respectively. This wavelength range enables one to detect noise in its near and far fields (depending upon the frequency used and the type of radiator source). The importance of studying the emitted noise at different lateral locations from the center of the power line, thus arised in order to obtain the relationship between noise level and distance for the lines surveyed.

3.2 ACTUAL SITES SELECTED

The sites were selected initially by satisfying as many of the criteria as possible. These sites are shown in Figure 3 and are as follows:

A.1 This site is on line CN-8 from Parkdale to Neepawa and the voltage is 115 KV.

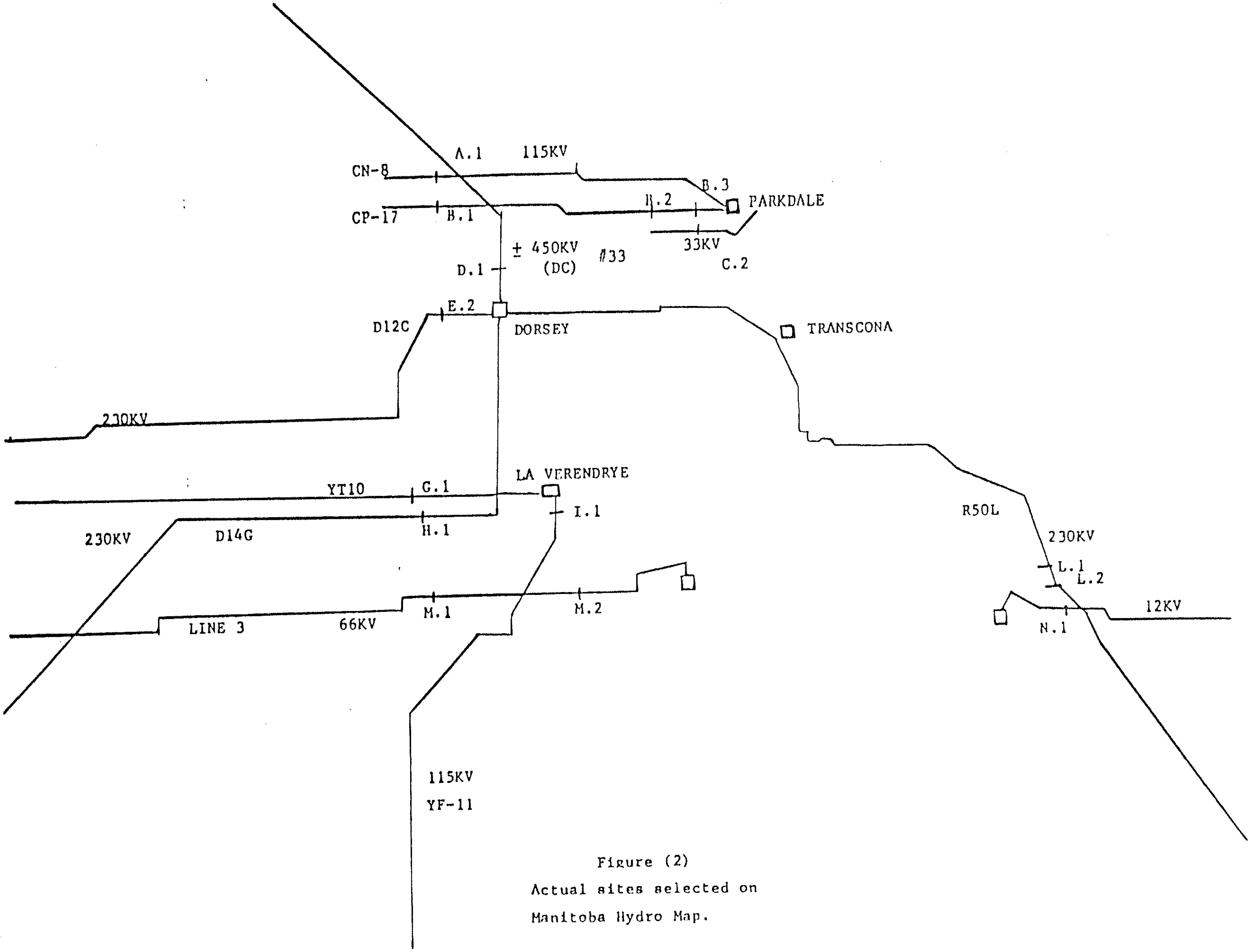


Figure (2)
Actual sites selected on
Manitoba Hydro Map.