Transmission Lines Modelling based on RLC Passive and Active Filter Design

Ahmed Qasim Turki*, Nashiren Farzilah Mailah and Ahmed H. Sabry

Department of Electrical & Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

ABSTRACT

This paper presents a transmission line (TL) modelling which is based upon vector fitting algorithm and RLC passive filter design. Frequency Response Analysis (FRA) is utilised for behaviour prediction and fault diagnosis. The utilities of the measured FRA data points need to be enhanced with suitable modelling category to facilitate the modelling and analysis process. This research proposes a new method for modelling the transmission line based on a rational approximation function which can be extracted through the Vector Fitting (VF) method, based on the frequency response measured data points. A set of steps needs to be implemented to achieve this by setting up an extracted partial fraction approximation, which results from a least square RMS error via VF. Active and passive filter design circuits are used to construct the model of the Transmission line. The RLC design representation was implemented for modelling the system physically while MATLAB Simulink was used to verify the results.

Keywords: Transmission lines modelling, vector fitting method

INTRODUCTION

The electrical power system mainly consists of three standard divisions: Generating Stations, Transmission system and Distribution System. The transmission line is the most vital energy corridor in a power system. (Pourmir & Akbarkehkhajavan, 2013). The performance of a power system depends mainly on the performance of the transmission lines in the system. Generally, transmission lines have three parameters: resistance, inductance, and capacitance and each one is distributed over the length of the line.

The classification of transmission lines depends on the accuracy and simplicity of the model. While the short transmission line model is simple, the longer line model is complex and the medium line is in between the two. Fidanboylu (2003) discusses a

transmission line method by using time domain synthesis approach. The parameters of each transmission line are determined using a constraint, nonlinear, least-squares optimisation technique performed in the time domain. The proposed modelling has several uses in microwave measurements material characterisation and microwave device modelling. (M & Semlyen, 1998) the author presents two highly accurate transmission line models. The first one is particularly suitable for overhead lines. In the second model, we use for propagation a modal decomposition of a constant transformation matrix and an optional phase domain correction term. Both models are computationally highly efficient due to their time domain realisations based on vector fitting. This research proposes a new method for modelling the transmission line based on a rational approximation function which can be extracted through the Vector Fitting (VF) method and RLC passive/active filter design.

VECTOR FITTING METHOD

Vector Fitting method is an approximation of a measured transmission line frequency response recently adopted in this application which is based on complex rational function models. Frequency dependent transmission line models have been used in the simulation of power system since the 1970s (Semlyen & Dabuleanu, 1975; Marti, 1982). The vector fitting method used in transmission line is transient. (Bjørn Gustavsen & Semlyen, 1998) According to the authors, this is a fast and robust method for the rational fitting of frequency domain responses well suited for both scalar and vector transfer functions (TF). The new method results in increased computational efficiency for transmission line models using modal decomposition with frequency dependent transformation matrices. This is due to the fact that the method allows the fitted elements of each eigenvector to share the same set of poles and that accurate fitting can be achieved with a relatively low number of poles. Gustavsen (2004) studied the time, delay identification for transmission lines modelling and found that to simply use the time delay of lossless propagation can lead to significant loss of accuracy of the rational approximation. Combining Brent's method with Vector Fitting (VF) optimises the time delay together with the poles and residues of the rational approximation. .

Past studies either addressed the modelling of transmission line in different categories or they used vector fitting algorithm with power transformer only. In this work, we propose the fundamentals of a method of TL modelling from measured data points based on RLC modelling of the rational approximation function attained from the VF method. The RLC modelling of this research uses the concept of passive and active filter representation of the partial fractions of the system transfer function.

PASSIVE FILTER DESIGN

The basic types of filter are Low-pass, high-pass, band pass, and band reject filter as shown in Figure 1(Ramsden, 2001).

The passive filter contains the resistor, inductor, and capacitor. The number of capacitor and inductor is equal to the higher power of frequency. The lumped values for each filter type for normalised frequency have been computed and tabulated (Matzner & Levy, 2008).
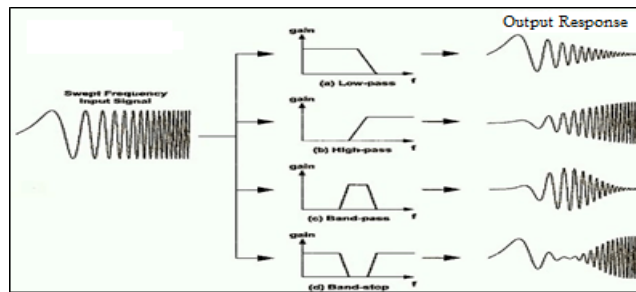
Figure 1. The effect of filter types on input signals

In this work, only passive filter circuits are utilised and described in detail.

Voltage divider circuit

The voltage divider circuits are very common. It is only two series resistors to simulate the reducing of the input signal.

$$\frac{vo}{vi} = \frac{R2}{R1+R2} \tag{1}$$

Low pass filter

Low Pass Filter (First order TF)

$$\frac{vo}{vi} = \frac{\frac{1}{RC}}{S+\frac{1}{RC}} \tag{2}$$

RLC second order Low Pass Filter

Low pass filter (Second-order TF)

$$\frac{vo}{vi} = \frac{\frac{1}{Sc}}{SL+\frac{1}{Rc}+R} = \frac{1}{S^2LC+1+SRC} = \frac{\frac{1}{LC}}{S^2+S\frac{R}{L}+\frac{1}{LC}} \tag{3}$$

Band Pass Filter

Band Pass Filter (Second-order TF)

$$\frac{vo}{vi} = \frac{R}{SL+\frac{1}{SC}+R} = \frac{SRC}{S^2LC+1+RSC} = \frac{S\frac{R}{L}}{S^2+S\frac{R}{L}+\frac{1}{LC}} \tag{4}$$

METHODOLOGY

The vector fitting algorithm has been used in different ways in (Adam SEMLYEN and Bjørn Gustavsen, 2000; Bjørn Gustavsen & Semlyen, 1999). MATLAB program was used in this

paper as it has suitable commands to get the parameters and the rational approximation function which are the key equations to acquire.

After the transmission line, RAF is obtained based on the FRA data points using VF method. The first step is to , set up the extracted partial fraction approximation, which results have less RMS error because of VF method, also expressed in eq. (5)

$$H(S) = \frac{r_1}{S - p_1} + \frac{r_2}{S - p_2} + \dots \frac{r_n}{S - p_n} + K \tag{5}$$

Eq. (5) consists of three parts as follows:-

- Real numbers, first order parts $\frac{r}{S + p}$
- Second order parts result from the result of two complex conjugate poles parts $\frac{as + b}{S^2 + cs + d}$
- Constants K.

Second, passive filter design circuit is conducted in order to build up the model that represents the TF of the transmission line by:-

- Implementation the required calculations to know the values of the circuits components.
- Using MATLAB Simulink to confirm the results.

Based on Bjørn Gustavsen and Semlyen (1999), the flowchart in Figure 2 describes the algorithm of the research, where the measured data points are presented as an input to the program. These data are changed to Cartesian form to generate a row of complex matrix for n dimension, and the process is described clearly in the flowchart.

Referring to the flowchart of Figure 2, the resultant RAF needs to be processed by some numerical filters to ignore the very low or the ineffective imaginary part from each element with respect to its combined real part. As an example, if one complex number has a value like pn= a*106+b*10-7j, then pn= a*106, then, rearranging eq. 1 all the rational partial parts of the system function again to sum each two pair that has complex conjugate numbers together to get second order partial function elements without imaginary part for all system RAF, so, as an example, eq. 5. could be ,changed to the following form.

$$H(S) = \frac{r_1}{S - p_1} + \frac{r_2}{S - p_2} + \frac{as + b}{S^2 + CS + d} + \dots + \frac{r_n}{S - p_n} + K \tag{6}$$

APPLICATION AND RESULTS

In order to validate the proposed method, a model mentioned in ("Power_piline," 2016) as shown in Figure 3 has been adopted to analyse the frequency response analysis (FRA). The modelling of the transmission line represents the TL behaviour to modelled together with this proposed method as shown in Figure 4 together with the curve fitting of the modelling procedure.
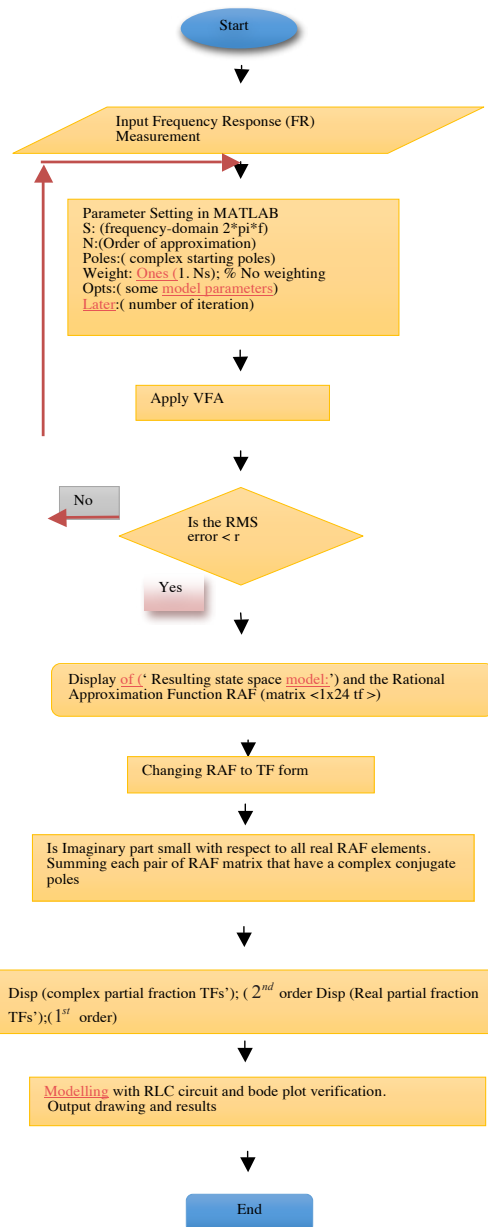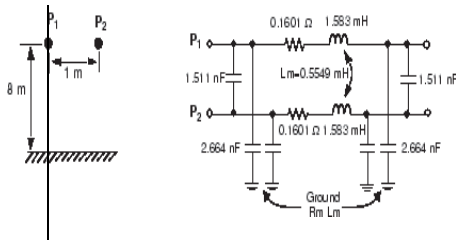
Figure 2. Flowchart of the proposed VF Algorithm
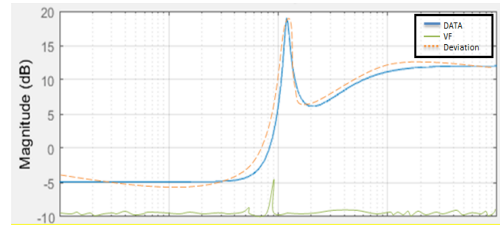
Figure 3. The adopted TL Model as a case study

Figure 4. Plotting the measured data with proposed VFA vs frequency

Referring to eq. 5 and the proposed algorithm of (Bjørn Gustavsen & Semlyen, 1999), the resultant Rational Approximation Function parameters can be listed as follows:

r =   -21.0633 + 0.0000i
           1.0510 + 0.0000i
           -0.4939 - 0.0546i
           -0.4939 + 0.0546i
P =   -4.8095 + 0.0000i
           -1.3091 + 0.0000i
           0.0593 + 1.1941i
           0.0593 - 1.1941i

K = 4

So, the partial fraction expansion for the above transfer functions are as follows:-

$$TF1 = \frac{-21}{S + 4.809}$$

$$TF2 = \frac{1.051}{S + 1.309}$$

$$TF3 = \frac{-(0.4939 + 0.0546i)}{S - (0.0593 + 1.194i)}$$

$$TF4 = \frac{-(0.4939 - 0.0546i)}{S - (0.0593 - 1.194i)}$$

After all transfer functions are obtained, the equation is rearranged to eq (5):

$$H(S) = \frac{-21}{S + 4.809} + \frac{1.051}{S + 1.309} + \frac{-(0.4939 + 0.0546i)}{S - (0.0593 + 1.194i)} + \frac{-(0.4939 - 0.0546i)}{S - (0.0593 - 1.194i)} + 4$$

Based on eq. (5), each of two complex conjugate poles must be added to each other as follows to obtain equation such as in eq. (6):-

$$H(S) = \frac{-21}{S + 4.809} + \frac{1.051}{S + 1.309} + \frac{-0.9878S + 0.189}{S^2 - 0.1186S + 1.429} + 4$$

As described in the flowchart of Figure 2, a sequence of filtering and complex conjugate pair summation has been implemented to avoid the presence of the imaginary part in all partial fractions of the RAF and therefore, the elements of eq. 6 are listed in Table 1.

Table 1 has the final transfer functions of first and second order group that would be translated to their respective RLC equivalent circuit. Hence, according to Eq. 6, all these partial fraction functions have the same input and accumulated output as represented in Figure 5.

Table 1
First and second order group

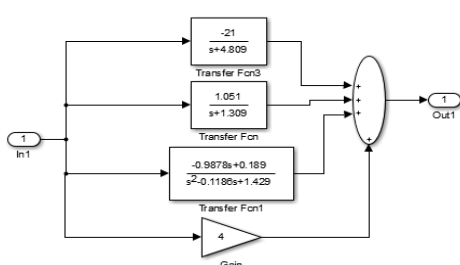| Second order	First order
$\dfrac{-0.9878S + 0.189}{S^2 - 0.1186S + 1.429}$	$\dfrac{-21}{S + 4.809}$
	$\dfrac{1.051}{S + 1.309}$

Figure 5. T.L modelling in terms of transfer function
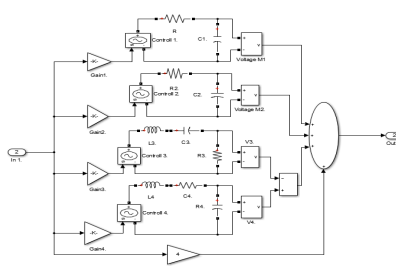

Figure 6. RLC passive circuit modelling for tested T.L

CONCLUSION

This paper discussed the results of transmission line modelling based on passive filter design and rational approximation function which can be extracted through the Vector Fitting (VF) method. The RLC circuit representation has been implemented for modelling the transmission line while MATLAB Simulink was used for verifying the results.

REFERENCES

Adam SEMLYEN ANDBjørn Gustavsen. (2000). Vector_Fitting_By_Pole_Relocation.Pdf.

Fidanboylu, K. M., Korkmaz, N., & Korkmaz, K. (2003, May). A transmission line modeling technique using time domain synthesis. In 2*003 IEEE International Symposium on Electromagnetic Compatibility, 2003. EMC'03*. (Vol. 1, pp. 331-334). IEEE.

Gustavsen, B. (2004, May). Time delay identification for transmission line modeling. In *8th IEEE Workshop on Signal Propagation on Interconnects, 2004. Proceedings*. (pp. 103-106). IEEE. http://doi.org/10.1109/SPI.2004.1409018

Gustavsen, B., & Semlyen, A. (1998). Simulation of transmission line transients using vector fitting and modal decomposition. *IEEE Transactions on Power Delivery, 13*(2), 605–611. http://doi.org/10.1109/61.660941

Gustavsen, B., & Semlyen, A. (1999). Rational approximation of frequency domain responses by vector fitting. *IEEE Transactions on Power Delivery, 14*(3), 1052-1061. http://doi.org/10.1109/61.772353

M, B. G., & Semlyen, A. (1998). Gustavsen" &I?), 13(2), 596–604.

Marti, J. R. (1982). Accurate Modeling of Frequency-Dependent Transmission Lines in Electromagnetic Transient Simulations. *IEEE Power Engineering Review, PER-2*(1), 29–30. http://doi.org/10.1109/MPER.1982.5519686

Matzner, S. H., Levy, H. M., & Ackerman, D. (2008). RF Laboratory Manual - Passive Filter Design. Retrieved 2016, February 25, from http://www.hit.ac.il/.upload/engineering/experiment_5_-_filter_design109.pdf

Pourmir, M. R., & Akbarkehkhajavan, A. (2013). Simulation Of Extra High Voltage Long Transmission Lines. *International Research Journal of Applied and Basic Sciences, 7*(7), 451–461.

Power_piline. (2016). *Mathworks*. Retrieved from http://www.mathworks.com/help/physmod/sps/powersys/ref/pisectionline.html;jsessionid=82e73e6c3de92aedeb4515f46c58

Ramsden, E. (2001). *An Introduction to Analog Filters | Sensors*. Retrieved 2016, February 25, from http://www.sensorsmag.com/sensors/electric-magnetic/an-introduction-analog-filters-1023

Semlyen, a., & Dabuleanu, a. (1975). Fast and accurate switching transient calculations on transmission lines with ground return using recursive convolutions. *IEEE Transactions on Power Apparatus and Systems, 94*(2), 561–571. http://doi.org/10.1109/T-PAS.1975.31884