

Intelligent Model to Obtain Initial and Final Conduction Angle of a Diode in a Half wave Rectifier with a Capacitor Filter

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Abstract. The half wave rectifier with a capacitor filter circuit is a typically non-linear case of study. It requires a hard work to solve it on analytic form. The main reason is due to the fact that the output voltage comes alternatively from the source and from the capacitor. This study describes a novel intelligent model to obtain the time when the changes of the sources occur. For the operation range, a large set of work points are calculated to create the dataset. To achieve the final solution, several simple regression methods have been tested. The novel model is verified empirically by using CAD software to simulate electronic circuits and by analytical methods. The novel model allows to obtain good results in all the operating range.

Keywords: Single phase wave rectifier, capacitance filter, neural networks

1 Introduction

Since semiconductors emerge in electronic field, one of the most researched circuits has been the rectifier. It is well-known that the function of the rectifiers, in general terms, is to obtain a continuous signal from an alternate signal [1]. These circuits are very common in applications like DC power supplies [2], peak signal detectors [3], and so on.

The basic rectifier is one of the most traditional circuits to learn electronic in the first courses [4]. Despite this, this type of schema could be not easy to solve and obtain its parameters. Fundamentally, the difficulty depends on: the number of phases of the source, the characteristics of the load and if it is controlled or a not controlled type [1].

A more specific example of this fact is the half wave rectifier with a capacitor filter. Due to the capacitive component added to a resistive load, the voltage has a less ripple wave [1]. Then the output voltage comes alternatively from

the source and from the capacitor [2]. The main problem is to know the time where the diode is in conduction (source provides the power to the load) or not (capacitor provides the power) [2]. As would be seen in the 'Case of study' section, this type of rectifier is not easy to solve in analytical form, due to the non-linear nature of its topology [3].

The knowledge of experts is used to create rule based systems models [5, 6]. Human experts extract rules from a system operation and then they structure it according to the system performance [5]. These methods allow to develop models to emulate the expert's behavior in a certain field [5, 7], and have been one of the most used methods in both research and operation [7].

The traditional regression methods are based on Multiple Regression Analysis (MRA) methods [8]. MRA-based methods are very popular among others because of their applications in many different fields [9, 10]. It is well-known that these methods have limitations [8, 11]. With the aim of solving these limitations, regression methods based on Soft Computing techniques have been proposed [12–17]. Taking into account this fact, a novel approach is proposed in this research. Therefore a novel Intelligent Model has been developed based on rules and Soft Computing techniques. The model allows obtaining the angles where a diode is conducting or not on the half wave rectifier with a capacitor filter circuit. Many Soft Computing techniques [18] have been tested in order to obtain the best fitness of the created model.

The rest of the paper is organized as follows: section 2 presents a brief description of the half wave rectifier with a capacitor filter is exposed. Then, the novel approach is presented in section 2.2. Section 3 describes the data set to achieve the model, and the intelligent regression techniques tested in this study to complement the experimental rule-based system. The results for the tested methods are described in section 4; and conclusions and future works are exposed at the end of the paper.

2 Case of study

2.1 Half wave rectifier with a capacitor filter circuit

The half wave rectifier with a capacitor filter circuit is shown in figure 1. The resistance R in parallel with capacitor filter C is fed for the voltage source V via diode D . The purpose of the capacitor is to reduce the variation in the output voltage, making it more like *DC Power*. The resistance represents a load and the capacitor represents a filter which is part of the rectifier circuit.

As the source decreases after the sinusoid peak, the capacitor discharges into the load resistor. Just at the same point, the voltage of the source becomes less than the output voltage, then the diode turns off, and the output voltage is a decaying exponential. The point where the diode turns off ($\omega t = \theta$) is determined by comparing the rates of change of the source and the capacitor voltages (figure 2). The angle, at which the diode turns on in the second period ($\omega t = 2\pi + \alpha$), is the point where the sinusoidal source reaches the same value as the decaying

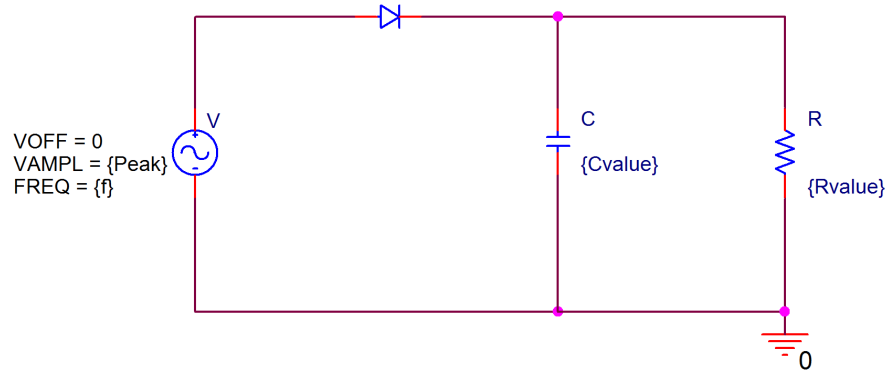


Fig. 1. Half wave rectifier with a capacitor filter circuit

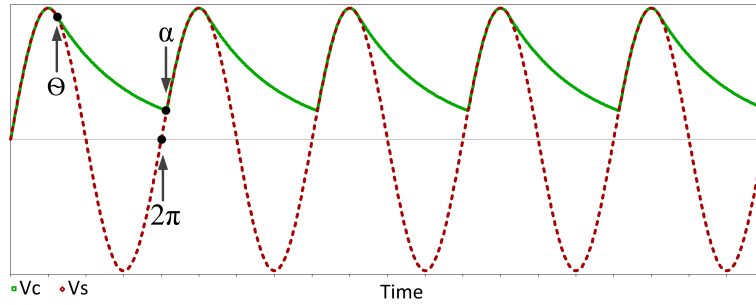


Fig. 2. Source and load voltage

exponential output. θ is obtained by equation 1, where ω is the frequency, R is the resistive value of the load and C is the capacitive value of the filter.

Two are the possibilities to obtain α value measured since 2π instant: The first one is when the capacitor discharge totally before the next positive period of the input source, the way to calculate the angle α is to use the equation 2. In this case the sign angle is negative.

The second one is obtained by solving the nonlinear equation 3. In this case the sign angle is positive.

$$\theta = -\tan^{-1}(\omega RC) + \pi \quad (1)$$

$$\alpha = 2\pi - \theta + \omega RC \ln \frac{1}{1000 \sin(\theta)} \quad (2)$$

$$\sin(\alpha) - (\sin(\theta)) e^{\frac{-(2\pi + \alpha - \theta)}{\omega RC}} = 0 \quad (3)$$

Figure 3 shows partially the operation range. On it, it is possible to appreciate two different regions depending of the α sign angle.

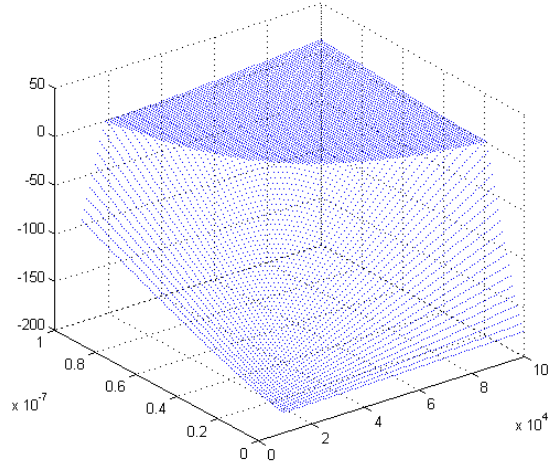


Fig. 3. Dataset to calculate α 's model

Figure 2 shows the source voltage (dots in red) and voltage in the load (continuous line in green). As can be shown in figure 2, the output voltage in the load is like *DC Power* but with a ripple voltage. θ and α instants are specified at figure 2.

As there is not any analytical solution for the equation 3, it is necessary to use numeric methods to solve the equation as the one mentioned before [1, 2].

2.2 Novel approach

The general schema of the proposed topology where the novel Intelligent Model is used to obtain the value of angles is illustrated in figure 4.

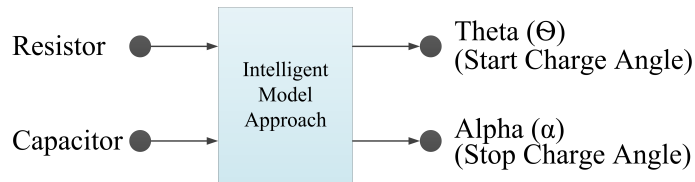


Fig. 4. General schema

As can be seen in figure 4, the model has two inputs: the resistor value and the capacitor value. The model provides the start discharge angle when diode turns off (θ) and the stop discharge angle when diode turns on (α).

The internal layout of the general schema is shown on figure 5. In figure 5 are identified the different parts of the proposal in a diagram block form. The novel approach has four blocks whose inputs are the same of the general schema (resistive value and the capacitive value of case of study). One of them is an Artificial Neural Networks (ANN) to obtain the α angle when it has a positive value (like non linear equation 3). Two of them are functions: the first one to obtain the θ angle according with equation 1, and the second one is to obtain α angle when it has a negative value according with equation 2. The fourth block, with the help of the multiplexer, that makes possible to choose between the blocks to obtain the α angle depending of its sign.

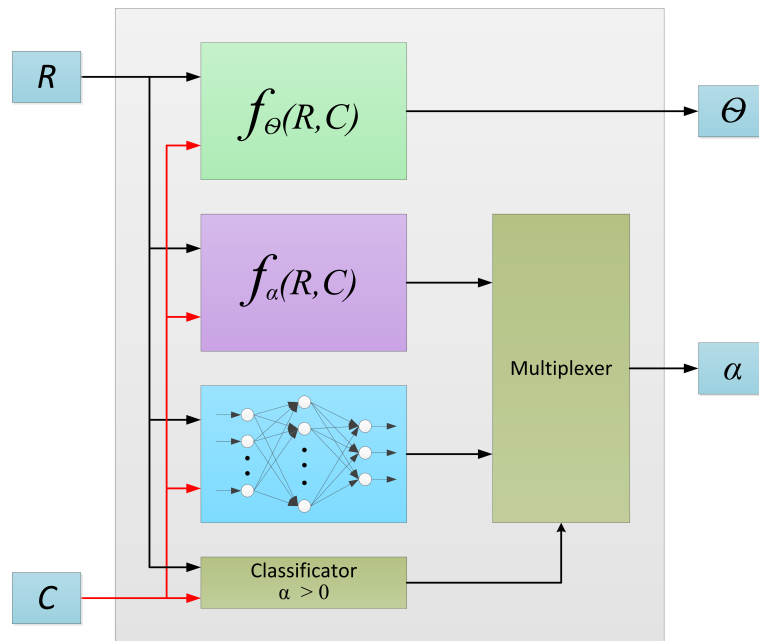


Fig. 5. Internal layout of the general schema

3 Model approach

3.1 Used techniques

The techniques tested in the study to select the best one, are described as follows.

Artificial Neural Networks (ANN): Multilayer Perceptron (MLP). A multilayer perceptron is a feedforward artificial neural network [18]. It is one

of the most typical ANNs due to its robustness and relatively simple structure. However the ANN architecture must be well selected to obtain good results.

The MLP is composed by one input layer, one or more hidden layers and one output layer, all of them made of neurons and with pondered connections between neurons of each layer.

Polynomial regression. Generally, a polynomial regression model [18] may also be defined as a linear summation of basis functions. The number of basis functions depends of the number of inputs of the model, and the degree of the polynomial used.

With a degree 1, the linear summation could be defined as the one shown in equation 4. The model becomes more complex as the degree increases (equation 5 shows a second degree polynomial for the model).

$$F(x) = a_0 + a_1x_1 + a_2x_2 \quad (4)$$

$$F(x) = a_0 + a_1x_1 + a_2x_2 + a_3x_1x_2 + a_4x_1^2 + a_5x_2^2 \quad (5)$$

Support Vector Regression (SVR), Least Square Support Vector Machine (LS-SVM). Support Vector Regression is a modification of the algorithm of the Support Vector Machines (SVM) for classification. In SVR the basic idea is to map the data into a high-dimensional feature space F via a non linear mapping and to do linear regression in this space [19].

Least Square formulation of SVM, are called LS-SVM. The approximation of the solution is obtained by solving a system of linear equations, and it is comparable to SVM in terms of generalization performance [20]. The application of LS-SVM to regression is known as LS-SVR (Least Square Support Vector Regression) [21]. In LS-SVR, the insensitive loss function is replace by a classical squared loss function, which constructs the Lagragian by solving a linear Karush-Kuhn-Tucker (KKT).

Logistic regression. The logistic regression is one of the most simplex algorithm used to classify [22]. As in the Intelligent Model described in this contribution has two different parts, it was necessary to make a classification of the samples to decided the model used to calculate the value of α angle.

The results of this classification is showed in table 4 in section 'Results'. The decision to used this method respond a principle of simplification and less computing requirements.

3.2 Case of study

The values of the resistor load went from 0.1Ω to $1M\Omega$. As this range is quite big, the values were not taking in a linear distribution; instead of that, 5 subranges were created with deferents steps each one (table 1).

Table 1. Ranges used for the load value

Initial value	Final value	Step size
0.1 Ω	100 Ω	1 Ω
100 Ω	1k Ω	10 Ω
1k Ω	10k Ω	100 Ω
10k Ω	100k Ω	1k Ω
100k Ω	1M Ω	10k Ω

In the same way, the values of the capacitor filter went from 1nF up to 1mF. This range was not as large as the resistor's one, but it was also sub-divided in 3 subranges (table 2).

Table 2. Ranges used for the capacitor filter value

Initial value	Final value	Step size
1nF	100nF	1nF
100nF	1 μ F	100nF
10 μ F	1mF	10 μ F

Whit this ranges of values, all typical working points of a rectifier are covered. Several scripts were implemented and used to calculate the starting point of the capacitor charge (angle θ), and the final angle of the capacitor discharge (angle α).

The calculation of the starting point is easy, because it's only necessary to apply the formula showed in equation 1.

Instead of the first angle, the stop discharging angle is calculated with two different formulas depending on the predicted sign of this angle (equations 3 and 2). One of these formulas is a non linear equation, and its solution is achieved by an iteration method. The number of iterations necessities depends on the desired precision. In this study, the precision is set to ± 0.01 rad, enough for the propose of this study, and better than the normal tolerance of the typical components.

3.3 Dataset conditioning

For obtaining the proposed model, it has been used a dataset which has 2 inputs variables (resistor load, and capacitor filter) and 2 outputs variables (θ and α angles). In figure 3 it is possible to see the difference depending on the sign of the angle α . That is the reason why it is necessary to use a classification system to calculate the value of this angle.

The dataset with a total of 139200 *samples*, has been divided into two dataset, training dataset (92800 *samples*, two thirds of the original dataset), and test dataset (46400 *samples*, one third of the original dataset).

Each model has been trained and later evaluated with the test dataset, in terms of the MSE (Mean Square Error).

4 Results

Once the models were trained, they were tested getting the results shown on tables 3 and 4 in terms of MSE.

The best result with ANN were achieved using only one hidden layer in each neural network, with an hyperbolic tangent, with 9 neurons in this hidden layer. With polynomial regression, best results were obtained with a 6 degree polynomial model. The best result with LS-SVR was achieved with parameters: $\gamma = 1.8324 e^7$ and $\sigma^2 = 2.0342$.

Based on the obtained results (tables 3), it is possible to conclude that the best models are ANN using 9 and 10 neurons in the hidden layer. LS-SVR is also getting good results (see table 3). The main reason to choose ANN is due to the required optimization process of LS-SVR for getting the best parameters (γ , σ) necessary for the training process, but once it has been trained, the computational cost is the same as for ANN.

Table 3. MSE of the different tested regression models

	$\alpha > 0$
ANN_12	0.0097
ANN_11	0.0086
ANN_10	0.0080
ANN_09	0.0014
ANN_08	0.0916
Poly_08	0.0422
Poly_07	0.0792
Poly_06	0.0036
Poly_05	0.0959
LS-SVM	0.0049

The best results to classification technique are obtained using a regularization constant with a value of 0.8. The confusion matrix for the training is shown in table 4.

Table 4. Confusion matrix of the classification

	$\alpha < 0$ (real)	$\alpha > 0$ (real)
$\alpha < 0$	15342	118
(test)	66.11%	0.56%
$\alpha > 0$	262	30678
(test)	0.25%	33.06%

5 Conclusions

With the novel intelligent model approach achieving very good results in general terms, getting the instants when the output voltage comes from the source or from de capacitor. With this proposal created based on intelligent techniques and rules is not necessary to solve the non-linear equation, both analytically or simulation.

As can be seen in 'Results' section, the best graphical adjustment of the objective data is obtained with ANN, where the MSE has a value of 0.0014. Other techniques allow good results like LS-SVM or Polynomial regression. With any of them, the time would be obtained, among others because the real components have normally tolerances bigger than 1%.

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