ISSN: 2455-3794

Contents lists available at http://www.albertscience.com

ASIO Journal of Engineering & Technological Perspective Research (ASIO-JETPR)

Volume 5, Issue 1, 2020, 28-30

ANALYSIS OF SERIES RL AND RC NETWORKS WITH SINUSOIDAL POTENTIAL SOURCES BY GUPTA TRANSFORM

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ARTICLE INFO

Research Article History

Received: 15th November, 2020
Accepted: 17th November, 2020

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ABSTRACT

The analysis of electric networks is an essential course for electrical and electronics engineering. The response of such networks is generally obtained by the different mathematical approaches and integral transforms. This paper presents a new integral transform called Gupta Transform for obtaining the complete response of the series RL and RC networks with sinusoidal potential sources. The response obtained will provide electric current (or electric charge) flowing through the series RL and RC network circuits. In this paper, the response of the series RL and RC networks is provided as a demonstration of the application of the new integral transform called Gupta Transform.

Index Terms: Gupta Transform; Current; Series RL and RC Networks; Response.

I. INTRODUCTION

The electric circuit of the series RL network consists of two passive electric elements: an inductor Ł and a resistor R, connected in series with a source of sinusoidal potential and the electric circuit of the series RC network consists of two passive electric elements: a capacitor C and a resistor R, connected in series with a source of sinusoidal potential. Such networks are used as a tuning or resonant circuit in the radio and television sets to resonate a particular frequency band from the wide range of radio frequency components, or in the chokes of luminescent tubes [1, 2, 3 & 4]. The Gupta Transform was proposed by the authors Rahul gupta and Rohit Gupta in recent years and generally, it has been applied in different areas of science and engineering [5, 6]. The response of electrical networks is generally obtained by the different mathematical approaches like the calculus approach [1-3], convolution theorem approach [4, 7, 8], and by various integral transforms like Laplace Transform [1-3], Mohand Transform [9, 10], Aboodh Transform [11], Elzaki Transform [12, 13, 14], Rohit Transform [15], residue theorem approach [16], Matrix method [17, 18, 19, 20], etc. This paper presents the use of a new integral transform called Gupta Transform for obtaining the complete response of the series RL and RC networks with a source of sinusoidal potential.

Basics of Gupta Transform

The Gupta Transform of g(y), y ≥ 0 is defined as [5, 6 & 21]

$\dot{R}\{g(y)\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, g(y)dy = G(q)$, provided that the integral is convergent. Here q may be a real or complex parameter and $\dot{R}$ is the Gupta Transform operator.

The Gupta Transform of elementary functions are given in [5, 6 & 21].

The inverse Gupta Transform of the function G(r) is denoted by $\dot{R}^{-1}\{G(r)\}$ or g (y).

If we write $\dot{R}\{g(y)\} = G(r)$, then $\dot{R}^{-1}\{G(r)\} = g(y)$, where $\dot{R}^{-1}$ is called the inverse Gupta Transform operator.

The Inverse Gupta Transform of elementary functions are given in [5, 6].

The Gupta Transform of some derivatives [5, 6] of g(y) are

$$\dot{R}\{g'(y)\} = q\dot{R}\{g(y)\} - \frac{1}{q^3}g(0),$$

$$\dot{R}\{g''(y)\} = q^2\dot{R}\{g(y)\} - \frac{1}{q^2}g(0) - \frac{1}{q^3}g'(0).$$

And so on.

doi no.: 10.2016-56941953; DOI Link :: http://doi-ds.org/doilink/11.2020-12824595/

II. FORMULATION

A. SERIES RL NETWORK CIRCUIT WITH SINUSOIDAL POTENTIAL SOURCE

We will take a series RL network to which a sinusoidal voltage source of potential $V_0 \sin\omega t$ is applied through a

key K as shown in figure 1.

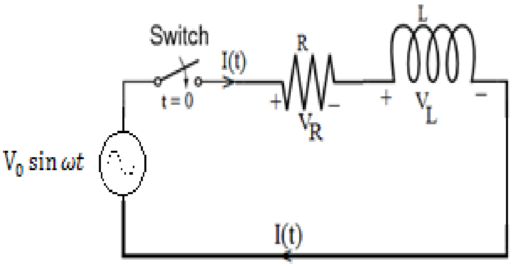

Figure 1: Series LR network with sinusoidal voltage source.

As the switch is closed at t = 0, the potential drops across the network elements are given by [1-4]

$V_R(t) = I(t)R,\ V_L(t) = L D_t[I(t)]$.

Therefore, the application of Kirchhoff's loop law to the loop shown in figure 2 provides

$V_R(t) + V_L(t) = V$

Or

$R\,I(t) + L D_t[I(t)] = V_0 \sin\omega t$ ..... (1) $\quad D_t \equiv \frac{d}{dt}$.

Differentiating (1), we get a differential equation of order 2 as given below:

$D_t^2[I(t)] + \frac{R}{L} D_t[I(t)] = \frac{V_0\,\omega}{L}\cos\omega t$ .... (2)

Solution governing equation by Gupta Transform

To solve equation (2), we first write the initial conditions as follows [1-4, 22]:

- Since the current in the inductor and the electric potential difference across the capacitor cannot change instantaneously, therefore, as the switch is closed at the instant t = 0, then I (0) = 0.
- Since I (0) = 0, therefore, (1) provides $D_t[I(0)] = 0$. The Gupta Transform [6, 21, 22,] of (2) provides

$$q^2\bar{I}(q) - \frac{1}{q^2}I(0) - \frac{1}{q^3}D_t[I(0)] + \frac{R}{L}\{q\,\bar{I}(q) - \frac{1}{q^3}I(0)\} = \frac{V_0\,\omega}{L}\frac{1}{q^2}\frac{1}{q^2+\omega^2} \;.......(3)$$

Applying $I(0) = 0$ and $D_t[I(0)] = 0$, (3) becomes,

$$q^2\bar{I}(q) + \frac{R}{L}q\,\bar{I}(q) = \frac{V_0\,\omega}{L}\frac{1}{q^2+\omega^2}$$

Or

$$\bar{I}(q) = \frac{V_0\,\omega}{L}\frac{1}{q^3}\frac{1}{q^2+\omega^2}\left[\frac{1}{q+\frac{R}{L}}\right]$$

This equation can be re written as

$\bar{I}(q) =$

$$\frac{V_0}{L}\{[\frac{L}{(\omega L)^2+R^2}(R\frac{1}{q^3}\frac{\omega}{q^2+\omega^2} - \omega L\frac{1}{q^2}\frac{1}{q^2+\omega^2})] + [\frac{\omega L^2}{(\omega L)^2+R^2}\frac{1}{q^3}\frac{1}{q+\frac{R}{L}}]\}$$

Taking inverse Gupta Transform [5], we have

$I(t) =$

$$\frac{V_0}{L}\{[\frac{L}{(\omega L)^2+R^2}(R\sin\omega t - \omega L\cos\omega t)] + [\frac{\omega L^2}{(\omega L)^2+R^2}e^{-(\frac{R}{L})t}]\}$$

Or

$I(t) = \frac{V_0}{\sqrt{(\omega L)^2+R^2}}$

$$\{[(\frac{R}{\sqrt{(\omega L)^2+R^2}}\sin\omega t - \frac{\omega L}{\sqrt{(\omega L)^2+R^2}}\cos\omega t)] + [\frac{\omega L}{\sqrt{(\omega L)^2+R^2}}e^{-(\frac{R}{L})t}]\}$$

.... (4)

Put $\frac{\omega L}{\sqrt{(\omega L)^2+R^2}} = \sin\emptyset$ and $\frac{R}{\sqrt{(\omega L)^2+R^2}} = \cos\emptyset$ such that $\tan\emptyset = \frac{\omega L}{R}$, then we can rewrite equation (4) as

$I(t) = \frac{V_0}{\sqrt{(\omega L)^2+R^2}}$

$\{[(\cos\emptyset\sin\omega t - \sin\emptyset\cos\omega t)] + [\sin\emptyset\, e^{-(\frac{R}{L})t}]\}$

Or

$$I(t) = \frac{V_0}{\sqrt{(\omega L)^2+R^2}}\{\sin(\omega t - \emptyset) + \sin\emptyset\, e^{-(\frac{R}{L})t}\} ..... (5)$$

This equation (5) provides the complete response of the series Ł – R network with a source of sinusoidal potential.

B. SERIES RC NETWORK CIRCUIT WITH SINUSOIDAL POTENTIAL SOURCE

The series R-C network circuit with a sinusoidal potential source (as shown in figure 2) is analyzed by the following equation [1-3]

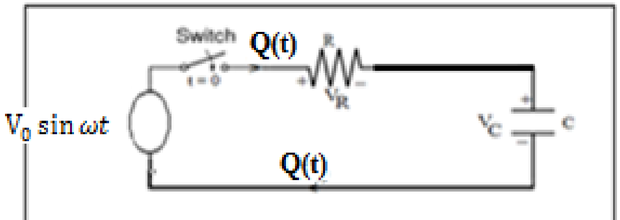

Figure 2: SERIES R-C NETWORK CIRCUIT WITH SINUSOIDAL POTENTIAL SOURCE

$$\dot{Q}(t)R + \frac{Q(t)}{C} = V_0\sin\omega t$$

Or

$$\dot{Q}(t) + \frac{1}{RC}Q(t) = \frac{V_0}{R}\sin\omega t \quad .....(6)$$

Here, $Q(t)$ is the instantaneous charge and Q (0) = 0.

The Gupta Transform [6, 21] of (6) gives

$$\{q\,\bar{Q}(q) - \frac{1}{q^3}Q(0)\} + \frac{1}{RC}\bar{Q}(q) = \frac{V_0}{R}\frac{1}{q^3}\frac{\omega}{q^2+\omega^2}$$

Put Q (0) = 0 we get

$$\{q\,\bar{Q}(q)\} + \frac{1}{RC}\bar{Q}(q) = \frac{V_0}{R}\frac{1}{q^3}\frac{\omega}{q^2+\omega^2}$$

$$\bar{Q}(q) = \frac{V_0}{R}\frac{1}{q^3}\frac{\omega}{(q^2+\omega^2)(q+\frac{1}{RC})}$$

$\bar{Q}(q) =$

$$\frac{V_0}{R}\{[\frac{RC}{(\omega RC)^2+1}(\frac{1}{q^3}\frac{\omega}{q^2+\omega^2} - \omega RC\frac{1}{q^2}\frac{1}{q^2+\omega^2})] + [\frac{\omega(CR)^2}{(\omega RC)^2+1}\frac{1}{q^3}\frac{1}{q+\frac{1}{RC}}]\}$$

Taking inverse Gupta Transform [5], we have

$Q(t) =$

$$\frac{V_0}{R}\{[\frac{RC}{(\omega RC)^2+1}(\sin\omega t - \omega RC\cos\omega t)] + [\frac{\omega(CR)^2}{(\omega RC)^2+1}e^{-(\frac{1}{RC})t}]\}$$

Or

Doi no.: 10.2016-56941953; DOI Link :: http://doi-ds.org/doilink/11.2020-12824595/

$$Q(t) = \frac{V_0}{\sqrt{(\omega RC)^2+1}}$$

$$\{[(\frac{C}{\sqrt{(\omega RC)^2+1}} \sin \omega t - \frac{\omega RC^2}{\sqrt{(\omega RC)^2+1}} \cos \omega t)] + [\frac{\omega RC^2}{\sqrt{(\omega RC)^2+1}} e^{-(\frac{1}{RC})t}]\}$$

.... (7)

Put $\frac{\omega RC^2}{\sqrt{(\omega RC)^2+1}} = \sin \emptyset$ and $\frac{C}{\sqrt{(\omega RC)^2+1}} = \cos \emptyset$ such that $\tan \emptyset = \omega RC$, then we can rewrite equation (7) as

$$I(t) = \frac{V_0}{\sqrt{(\omega RC)^2+1}}$$

$$\{[(\cos \emptyset \sin \omega t - \sin \emptyset \cos \omega t)] + [\sin \emptyset\, e^{-(\frac{1}{RC})t}]\}$$

Or

$$Q(t) = \frac{V_0}{\sqrt{(\omega RC)^2+1}} \{\sin(\omega t - \emptyset) + \sin \emptyset\, e^{-(\frac{1}{RC})t}\} \text{.... (8)}$$

This equation (8) provides the complete response of the series RC network with a source of sinusoidal potential.

III. CONCLUSION

In this paper, a new integral transform called Gupta Transform has successfully applied for determining the complete response (electric current) of a series RL and RC networks with a source of sinusoidal potential. The results obtained are the same as obtained with other approaches [1-4]. This approach brought up the Gupta Transform as a new and powerful tool for determining the response of network circuits.

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How to cite the article?

Rahul Gupta, Rohit Gupta, Dinesh Verma, Analysis of series RL and RC networks with sinusoidal potential sources by gupta transform, *ASIO Journal of Engineering & Technological Perspective Research (ASIO-JETPR), 2020, 5(1): 28-30.*

Doi no.: 10.2016-56941953; DOI Link :: http://doi-ds.org/doilink/11.2020-12824595/