

# LAPLACE TRANSFORMS AND ITS APPLICATIONS

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**Abstract** Laplace transform is a very powerful mathematical tool applied in various areas of engineering and science. With the increasing complexity of engineering problems, Laplace transforms help in solving complex problems with a very simple approach just like the applications of transfer functions to solve ordinary differential equations. This paper will discuss the applications of Laplace transforms in the area of physics followed by the application to electric circuit analysis. A more complex application on Load frequency control in the area of power systems engineering is also discussed.

## I. INTRODUCTION

Laplace transform is an integral transform method which is particularly useful in solving linear ordinary differential equations. It finds very wide applications in various areas of physics, electrical engineering, control engineering, optics, mathematics and signal processing. The Laplace transform can be interpreted as a transformation from the time domain where inputs and outputs are functions of time to the frequency domain where inputs and outputs are functions of complex angular frequency.

In order for any function of time  $f(t)$  to be Laplace transformable, it must satisfy the following Dirichlet conditions [1]:

- $f(t)$  must be piecewise continuous which means that it must be single valued but can have a finite number of finite isolated discontinuities for  $t > 0$ .
- $f(t)$  must be exponential order which means that  $f(t)$  must remain less than  $Se^{-\alpha_0 t}$  as  $t$  approaches  $\infty$  where  $S$  is a positive constant and  $\alpha_0$  is a real positive number.

If there is any function  $f(t)$  that satisfies the Dirichlet conditions, then,

$F(s) = \int_0^{\infty} f(t)e^{-st} dt$  written as  $L\{f(t)\}$  is called the Laplace transformation of  $f(t)$ . Here,  $s$  can be either a real variable or a complex quantity.

The integral  $\int_0^{\infty} f(t)e^{-st} dt$  converges if  $\int_0^{\infty} |f(t)e^{-st}| dt < \infty, s = \sigma + j\omega$

### A. Some Important Properties of Laplace Transforms

The Laplace transforms of different functions can be found in most of the mathematics and engineering books and hence, is not included in this paper. Some of the very important properties of Laplace transforms which will be used in its applications to be discussed later on are described as follows:[1][2]

#### • Linearity

The Laplace transform of the linear sum of two Laplace transformable functions  $f(t) + g(t)$  is given by

$$L\{f(t) + g(t)\} = F(s) + G(s)$$

#### • Differentiation

If the function  $f(t)$  is piecewise continuous so that it has a continuous derivative  $f'(t)$  of order  $n-1$  and a sectionally continuous derivative  $f''(t)$  in every finite interval  $0 \leq t \leq T$ , then let,  $f(t)$  and all its derivatives through  $f^{(n-1)}(t)$  be of exponential order  $e^{at}$  as  $t \rightarrow \infty$ .

Then, the transform of  $f''(t)$  exists when  $Re(s) > a$  and has the following form:

$$L\{f''(t)\} = s^2 F(s) - s f'(0+) - f(0+) - \dots - s^{n-1} f^{(n-1)}(0+)$$

#### • Time delay

The substitution of  $t - \lambda$  for the variable  $t$  in the transform  $L\{f(t)\}$  corresponds to the multiplication of the function  $F(s)$  by  $e^{-s\lambda}$ , that is

$$L\{f(t - \lambda)\} = e^{-s\lambda} F(s)$$

## II. APPLICATIONS OF LAPLACE TRANSFORMS

This section describes the applications of Laplace transforms in the areas of science and engineering. At first, simple application in the area of Physics and Electric Circuit theory is presented which will be followed by a more complex application to power system which includes the description of Load Frequency Control (LFC) for transient stability studies.

### A. Application in Physics

A very simple application of Laplace transform in the area of physics could be to find out the harmonic vibration of a beam which is supported at its two ends [3].

Let us consider a beam of length  $l$  and uniform cross section parallel to the  $yz$  plane so that the normal deflection  $w(x,t)$  is measured downward if the axis of the beam is towards  $x$  axis. The basic equation defining this phenomenon is as given below:

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### **Table of Contents Applications Of Fuzzy Laplace Transforms Springer**

1. Understanding the eBook Applications Of Fuzzy Laplace Transforms Springer
  - The Rise of Digital Reading Applications Of Fuzzy Laplace Transforms Springer
  - Advantages of eBooks Over Traditional Books
2. Identifying Applications Of Fuzzy Laplace Transforms Springer
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Applications Of Fuzzy Laplace Transforms Springer
  - User-Friendly Interface

4. Exploring eBook Recommendations from Applications Of Fuzzy Laplace Transforms Springer
  - Personalized Recommendations
  - Applications Of Fuzzy Laplace Transforms Springer User Reviews and Ratings
  - Applications Of Fuzzy Laplace Transforms Springer and Bestseller Lists
5. Accessing Applications Of Fuzzy Laplace Transforms Springer Free and Paid eBooks
  - Applications Of Fuzzy Laplace Transforms Springer Public Domain eBooks
  - Applications Of Fuzzy Laplace Transforms Springer eBook Subscription Services
  - Applications Of Fuzzy Laplace Transforms Springer Budget-Friendly Options
6. Navigating Applications Of Fuzzy Laplace Transforms Springer eBook Formats
  - ePub, PDF, MOBI, and More
  - Applications Of Fuzzy Laplace Transforms Springer Compatibility with Devices
  - Applications Of Fuzzy Laplace Transforms Springer Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Applications Of Fuzzy Laplace Transforms Springer
  - Highlighting and Note-Taking Applications Of Fuzzy Laplace Transforms Springer
  - Interactive Elements Applications Of Fuzzy Laplace Transforms Springer
8. Staying Engaged with Applications Of Fuzzy Laplace Transforms Springer
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Applications Of Fuzzy Laplace Transforms Springer
9. Balancing eBooks and Physical Books Applications Of Fuzzy Laplace Transforms Springer
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Applications Of Fuzzy Laplace Transforms Springer
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Applications Of Fuzzy Laplace Transforms Springer
  - Setting Reading Goals Applications Of Fuzzy Laplace Transforms Springer
  - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Applications Of Fuzzy Laplace Transforms Springer
  - Fact-Checking eBook Content of Applications Of Fuzzy Laplace Transforms Springer
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
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