A Novel Integral Transform: INEM - Transform

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Abstract— *In this paper, we present a novel transform namely INEM – Transform , involving a lot of potential new or known transform basic characteristics of the new transform were examined in this work as special cases., authors first derived the INEM – transform of basic mathematical functions ,theorem of linearity ,theorem of derivatives and the definition of inverse formula .a novel transformation used to address specific initial value problems of higher order ,some illustrative examples, and use of application in two applications: finding the blood glucose concentration and finding the aortic pressure presented in this work.*

Keywords— Integral transform , INEM transform, Ordinary differential equations , initial conditions

I. INTRODUCTION

Due to their three key characteristics—first, their simplicity, second, their ability to provide precise results, and third, their ability to do so without requiring time-consuming calculation work—integral transforms are currently the method of choice for researchers when it comes to solving problems in science, social science, and engineering. New integral transforms were developed by researchers. [Abaoub-Shkheam [1], Rishi [2], Kamal[3], Mohand[4] , Formable[5], ARA [6] NE [7], α-Sumudu[8]] .
Kharde in [9] In order to solve differential equations with constant coefficients, researchers successfully investigate the fundamental Yang transform properties.Mohamed in [10] introduce a novel generalized integral transform that can be used to solve specific initial boundary value problems and involves many potential known variables.Hassan in [11] With and without constant coefficients having convolution terms, the Sumudu transform was used to solve the linear ordinary differential equation.Kaklij in [12] introduced the definition of Double New General Integral Transform and some properties , Intidhar in [13] in order to solve the IVP including the systemof ODEs, the Sadiq and complex Sadiq integral transformations were discussed in detail., Saed in [14] Partial differential equations can be solved using double integral transformations, which reduce them to to straightforward algebraic equations. Ali in [15] two parametric SEE transformations in solving differential equations has been shown . Eman in[16] Faltung type First-order Volterra integro-differential equation problems have been addressed using complex SEE integral transform.. Hossein in [17] In the Laplace transform class, introduce a general integral transform that can be used to solve fractional order integral equations, higher order initial value problems and integral equations There are many applications and different way to solve equation in the science [18-19-20].
The significance of this transformation lies in the fact that, as a function with parameters, the transform kernel is more general than the Laplace transform.
We discuss in this paper purpose anew integral transform called INEM – Transform, we introduce the definitions of transform - definition of modified transform and derived transform of some basic mathematical function , also some theorems of new transform was present , Transform through applications, we finally apply it to a some ordinary differential equations.

II. DEFINITIONS AND THEOREMS

This section serves to introduce the definitions of INEM – Transform, together with new transform of some functions ,and theorems

Definition1: let $f(t)$ be a integrable function defined for $t \geq 0$,$p(v), q(v)$ are afunctions of parameter v,we defined INEM – transform of $f(t)$ by the formula :

$$E\big(f(t)\big) = I(v) = p(v)\int_0^\infty f(t)e^{-(q(v))^{\frac{1}{n}}t}\,dt \qquad \dots (1)$$

Where $n \in Z^+$

Let for all $t \geq 0, f(t)$ is piecewise contionus function as well as satisfies $\lfloor f(t) \rfloor \leq Me^{-kt}$ then $I(v)$ is exist for all $\big(q(v)\big)^{\frac{1}{n}} > k \quad ,k \in N, M \neq 0.$

Note : $p(v)$ may be Trigonometric functions , Hyperbolic functions, polynomial function ,fractional function …etc .

Definition 2: let $f(t)$ is an integrable function with the defined for $t \geq 0$,$p(v), q(v)$ are a functions of parameter v, we defined modified INEM – transform of $f(t)$ by the formula :

$$E_a(f(t)) = I_a(v) = p(v)\int_0^\infty f(t)a^{-(q(v))^{\frac{1}{n}}t}\,dt \qquad \dots (2)$$

Where $n \in Z$, $a > 0$

II-1 INEM – transform of frequently functions:

1- Consider the function $f(t)$,defined by $f(t) = 1, t > 0$, then by definition of new transformation :

$$E(1) = I(v) = p(v)\int_0^\infty 1e^{-(q(v))^{\frac{1}{n}}t}\,dt$$

$$I(v) = \left[\frac{-p(v)}{(q(v))^{\frac{1}{n}}}e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty\right] = \frac{p(v)}{(q(v))^{\frac{1}{n}}}$$

Similarly if $f(t) = a$,where a is constant then

$$E(a) = \frac{ap(v)}{(q(v))^{\frac{1}{n}}}$$

2- consider the function $f(t)$,defined by $f(t) = t, t > 0$, then by definition of new transformation :

$$E(t) = I(v) = p(v)\int_0^\infty te^{-(q(v))^{\frac{1}{n}}t}\,dt$$

$$I(v) = p(v)\left[\frac{-t}{(q(v))^{\frac{1}{n}}}e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty - \frac{1}{(q(v))^{\frac{2}{n}}}e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty\right]$$

$$E(t) = I(v) = \frac{p(v)}{(q(v))^{\frac{2}{n}}}$$

Now if $f(t) = t^2$ then by definition of new transformation :

$$E(t^2) = I(v) = p(v)\int_0^\infty t^2e^{-(q(v))^{\frac{1}{n}}t}\,dt$$

$$I(v) = p(v)\left[\frac{-t^2}{(q(v))^{\frac{1}{n}}}e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty - \frac{2t}{(q(v))^{\frac{2}{n}}}e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty - \frac{2}{(q(v))^{\frac{3}{n}}}e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty\right]$$

$$E(t^2) = I(v) = \frac{2p(v)}{(q(v))^{\frac{3}{n}}}$$

In general $E(t^r) = I(v) = \frac{r!p(v)}{(q(v))^{\frac{r+1}{n}}}$,where $r \in z^+$

3- consider the function $f(t) = e^{at}$, a is constant , then by definition of new transformation :

$$E(e^{at}) = I(v) = p(v)\int_0^\infty e^{at}e^{-(q(v))^{\frac{1}{n}}t}\,dt$$

$$E(e^{at}) = I(v) = p(v)\int_0^\infty e^{-\left[(q(v))^{\frac{1}{n}}-a\right]t}\,dt$$

$$E(e^{at}) = \frac{-p(v)}{(q(v))^{\frac{1}{n}}-a}e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty = \frac{p(v)}{(q(v))^{\frac{1}{n}}-a}$$

4- consider the function $f(t) = \sin at$, a is constant , then by definition of new transformation :

$$E(\sin at) = I(v) = p(v)\int_0^\infty \sin at\, e^{-(q(v))^{\frac{1}{n}}t}\,dt$$

$$E(\sin at) = \frac{-p(v)e^{-(q(v))^{\frac{1}{n}}t}\left[-(q(v))^{\frac{1}{n}}\sin at - a\cos at\right]}{(q(v))^{\frac{2}{n}}+a^2}\Bigg|_0^\infty$$

$$E(\sin at) = \frac{ap(v)}{(q(v))^{\frac{2}{n}}+a^2}$$

Similarly

$$E(\cos at) = \frac{p(v)(q(v))^{\frac{1}{n}}}{(q(v))^{\frac{2}{n}}+a^2}$$

Property.(Linearty property) 1: let $af_1(t)$ and $bf_1(t)$ have INEM – Transform $I_1(v)$ and $I_2(v)$ then the INEM – Transform of

$$E[af_1(t) \mp bf_1(t)] = aI_1(v) + bI_1(v)$$

Proof : $E[af_1(t) \mp bf_1(t)] = p(v)\int_0^\infty [af_1(t) \mp bf_1(t)]e^{-(q(v))^{\frac{1}{n}}t}\,dt$

$$= p(v)\left[a\int_0^\infty f_1(t)e^{-(q(v))^{\frac{1}{n}}t}dt \mp b\int_0^\infty f_1(t)e^{-(q(v))^{\frac{1}{n}}t}\,dt\right]$$

$$= aI_1(v) + bI_1(v)$$

For example if $f(t) = \sinh at$ then by above Property the INEM – Transform is

$$E\{\sinh at\} = E\left\{\frac{e^{at}-e^{-at}}{2}\right\} = \frac{1}{2}E\{e^{at}-e^{-at}\}$$

$$= \frac{1}{2}\left[\frac{p(v)}{(q(v))^{\frac{1}{n}}-a} - \frac{p(v)}{(q(v))^{\frac{1}{n}}+a}\right] = \frac{ap(v)}{(q(v))^{\frac{2}{n}}-a^2}$$

And $E\{\cosh at\} = \frac{(q(v))^{\frac{1}{n}}p(v)}{(q(v))^{\frac{2}{n}}-a^2}$

Theorem 1 : let $f(t)$ is definable function where $(q(v))^{\frac{1}{n}}$ are positive real function ,then

1) $E\{f'(t)\} = (q(v))^{\frac{1}{n}}I(v) - p(v)f(0)$

2) $E\{f''(t)\} = (q(v))^{\frac{2}{n}}I(v) - p(v)(q(v))^{\frac{1}{n}}f(0) - p(v)f'(0)$

Proof :

1) in view of (1) we have

$$E\{f'(t)\} = I(v) = p(v)\int_0^\infty f'(t)e^{-(q(v))^{\frac{1}{n}}t}\,dt$$

$$= p(v)\left[f(t)e^{-(q(v))^{\frac{1}{n}}t}\Big|_0^\infty + (q(v))^{\frac{1}{n}}\int_0^\infty f(t)e^{-(q(v))^{\frac{1}{n}}t}\,dt\right]$$

$$= (q(v))^{\frac{1}{n}}I(v) - p(v)f(0)$$

2) $E\{f''(t)\} = E\left\{\frac{df'(t)}{dt}\right\} = (q(v))^{\frac{1}{n}}E\{f'(t)\} - p(v)f'(0)$

$$= (q(v))^{\frac{1}{n}}\left[(q(v))^{\frac{1}{n}}I(v) - p(v)f(0)\right] - p(v)f'(0)$$

$$= \left(q(v)\right)^{\frac{2}{n}} I(v) - p(v)\left(q(v)\right)^{\frac{1}{n}} f(0) - p(v)f'(0)$$

In general $E\{f^{(r)}(t)\} = \left(q(v)\right)^{\frac{r}{n}} I(v) - \sum_{i=1}^{r-1} p(v)\left(q(v)\right)^{\frac{r-i}{n}} f^{(i-1)}(0)$

Defintion 3: if $I(v)$ represents the INEM – Transform of the function $f(t)$,the inverse transformation of the function $I(v)$ which is symbolized by $I^{-1}(v)$ as a function of t,that is $I^{-1}\left(I(v)\right) = f(t)$.

III. Solving Higher Order non Homogenous ODE with Variable and Constant Coefficient :

So In this section ,we use INEM – Transform to solve higher order non homogenous ODE with variable and constant coefficient .

Example 1:consider thew following second order ODE with constant coefficient:

$$3y'' - 5y' + 2y = t^2 \qquad \dots (3)$$

$y(0) = 1, y'(0) = 2$

By applying INEM – Transform of both sided of (3) we get

$E\{3y'' - 5y' + 2y\} = E\{t^2\}$

Use above propriety and theorem we obtain

$E\{3y''\} - 5\{y'\} + 2\{y\} = E\{t^2\}$

$3\left(q(v)\right)^{\frac{2}{n}} I(v) - 3p(v)\left(q(v)\right)^{\frac{1}{n}} y(0) - 3p(v)y'(0) - 5\left(q(v)\right)^{\frac{1}{n}} I(v) + 5p(v)y(0) + 2I(v) = \frac{2p(v)}{\left(q(v)\right)^{\frac{3}{n}}}$

By swapping out the initial conditions in the equation above, we get

$$\left[3\left(q(v)\right)^{\frac{2}{n}} - 5\left(q(v)\right)^{\frac{1}{n}} + 2\right] I(v) = \frac{2p(v)}{\left(q(v)\right)^{\frac{3}{n}}} + 3p(v)\left(q(v)\right)^{\frac{1}{n}} + p(v)$$

$$I(v) = \frac{p(v)\left(3\left(q(v)\right)^{\frac{4}{n}} + \left(q(v)\right)^{\frac{3}{n}} + 2\right)}{\left(3\left(q(v)\right)^{\frac{2}{n}} - 5\left(q(v)\right)^{\frac{1}{n}} + 2\right)\left(q(v)\right)^{\frac{3}{n}}}$$

$$I(v) = \frac{p(v)\left(3\left(q(v)\right)^{\frac{4}{n}} + \left(q(v)\right)^{\frac{3}{n}} + 2\right)}{\left(3\left(q(v)\right)^{\frac{1}{n}} - 2\right)\left(\left(q(v)\right)^{\frac{1}{n}} - 1\right)\left(q(v)\right)^{\frac{3}{n}}}$$

Then

$$I(v) = \frac{-117p(v)}{4\left(3\left(q(v)\right)^{\frac{1}{n}} - 2\right)} + \frac{6p(v)}{\left(\left(q(v)\right)^{\frac{1}{n}} - 1\right)} + \frac{19p(v)}{4\left(q(v)\right)^{\frac{1}{n}}} + \frac{5p(v)}{2\left(q(v)\right)^{\frac{2}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{3}{n}}} \qquad \dots (4)$$

Now applying I^{-1} of both sided of (4) we get

$$f(t) = I^{-1}\left\{\frac{-117p(v)}{4\left(3\left(q(v)\right)^{\frac{1}{n}} - 2\right)}\right\} + I^{-1}\left\{\frac{6p(v)}{\left(\left(q(v)\right)^{\frac{1}{n}} - 1\right)}\right\} + I^{-1}\left\{\frac{19p(v)}{4\left(q(v)\right)^{\frac{1}{n}}}\right\} + I^{-1}\left\{\frac{5p(v)}{2\left(q(v)\right)^{\frac{2}{n}}}\right\} + I^{-1}\left\{\frac{p(v)}{\left(q(v)\right)^{\frac{3}{n}}}\right\}$$

$$y(t) = \frac{-39}{4} e^{\frac{2}{3}t} + 6e^t + \frac{1}{2}t^2 + \frac{5}{2}t + \frac{19}{4}$$

Example 2.:consider the following four order ODE with variable coefficient:

$$\frac{y^{(4)}}{\cos t} = \sec t + \tan t \qquad \dots (5)$$

$y(0) = 0, y'(0) = 0. y''(0) = -1, y'''(0) = 1$

$$y^{(4)} = 1 + \sin t \qquad \dots (6)$$

By applying INEM – Transform of both sided of (6) we get

$E\{y^{(4)}\} = E\{1 + \sin t\}$

Use above propriety and theorem we obtain

$$\left(q(v)\right)^{\frac{4}{n}} I(v) - p(v)\left(q(v)\right)^{\frac{3}{n}} y(0) - p(v)\left(q(v)\right)^{\frac{2}{n}} y'(0) - p(v)\left(q(v)\right)^{\frac{1}{n}} y''(0) - p(v)y'''(0) = \frac{p(v)}{\left(q(v)\right)^{\frac{1}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}} + 1}$$

By replacing the initial conditions on above equation we have

$$\left(q(v)\right)^{\frac{4}{n}} I(v) = \frac{p(v)}{\left(q(v)\right)^{\frac{1}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}} + 1} - p(v)\left(q(v)\right)^{\frac{1}{n}} + p(v)$$

$$I(v) = \frac{p(v)}{\left(q(v)\right)^{\frac{5}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}\left(\left(q(v)\right)^{\frac{2}{n}} + 1\right)} - \frac{p(v)}{\left(q(v)\right)^{\frac{3}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}}$$

$$I(v) = \frac{p(v)}{\left(q(v)\right)^{\frac{5}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}} + 1} - \frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}}} - \frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}} - \frac{p(v)}{\left(q(v)\right)^{\frac{3}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}} \qquad \dots (7)$$

Now applying I^{-1} of both sided of (8) we get

$$I(v) = \frac{p(v)}{\left(q(v)\right)^{\frac{5}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}} + 1} - \frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}} - \frac{p(v)}{\left(q(v)\right)^{\frac{3}{n}}} + \frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}}$$

$$y = I^{-1}\left\{\frac{p(v)}{\left(q(v)\right)^{\frac{5}{n}}}\right\} + I^{-1}\left\{\frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}} + 1}\right\} - I^{-1}\left\{\frac{p(v)}{\left(q(v)\right)^{\frac{2}{n}}}\right\} + I^{-1}\left\{\frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}}\right\} - I^{-1}\left\{\frac{p(v)}{\left(q(v)\right)^{\frac{3}{n}}}\right\} + I^{-1}\left\{\frac{p(v)}{\left(q(v)\right)^{\frac{4}{n}}}\right\}$$

$$y = \frac{1}{24}t^4 + \frac{1}{12}t^3 - \frac{1}{2}t^2 - t + \sin t$$

IV .IMPLEMENTATION

This section presents the implementation of the INEM – Transform on two distinct cardiovascular models.

Implementation (Blood Glucose Concentration) 1:

During continuous intravenous glucose injection, the concentration of glucose in the blood is $G(t)$exceeding the baseline value at the start of the infusion. The function $G(t)$satisfies the initial value problem (I.V.P.), [21].

$G'(t) + kG(t) = \frac{\alpha}{\gamma}$ … (8)

Where $G(0) = 0, t > 0$

The variables in this equation are k, α, and γ, which respectively represent the constant velocity of elimination, the rate of infusion, and the volume in which glucose is distributed.

The INEM – Transform technique will be utilized to assess the concentration of glucose present in the bloodstream.

Upon bilateral application of the INEM – Transform to equation (8), the resulting expression is obtained:

$$E\{G'(t) + kG(t)\} = E\left\{\frac{\alpha}{\gamma}\right\}$$

Let $E\{G(t)\} = I(v)$,

Use above propriety and theorem we obtain

$$\left(q(v)\right)^{\frac{1}{n}} I(v) - p(v)G(0) + kI(v) = \frac{\frac{\alpha}{\gamma}p(v)}{\left(q(v)\right)^{\frac{1}{n}}}$$

By swapping out the initial conditions in the equation above, we get

$$\left(\left(q(v)\right)^{\frac{1}{n}} + k\right) I(v) = \frac{\frac{\alpha}{\gamma}p(v)}{\left(q(v)\right)^{\frac{1}{n}}}$$

$$I(v) = \frac{\frac{\alpha}{\gamma}p(v)}{\left(q(v)\right)^{\frac{1}{n}}\left(\left(q(v)\right)^{\frac{1}{n}} + k\right)}$$

$$I(v) = \frac{\frac{\alpha}{\gamma k}p(v)}{\left(q(v)\right)^{\frac{1}{n}}} - \frac{\frac{\alpha}{\gamma k}p(v)}{\left(\left(q(v)\right)^{\frac{1}{n}} + k\right)}$$

Now applying I^{-1} of both sided of a bove equation we get

$$G(t) = I^{-1}\left\{\frac{\frac{\alpha}{\gamma k}p(v)}{\left(q(v)\right)^{\frac{1}{n}}}\right\} - I^{-1}\left\{\frac{\frac{\alpha}{\gamma k}p(v)}{\left(\left(q(v)\right)^{\frac{1}{n}} + k\right)}\right\}$$

$$G(t) = \frac{\alpha}{\gamma k} - \frac{\alpha}{\gamma k}e^{-kt}$$

Implementation (Aorta Pressure) 2:

The heart's contraction facilitates the transportation of blood into the aorta. The initial value problem denoted by [21] is concerned with the aortic pressure function $f(t)$ as:

$f'(t) + \frac{c}{k}f(t) = cA\sin wt$ …(9)

Where $f(0) = 0, t > 0$

The variables in this equation are k, c, A, and w, are constants.

The INEM – Transform technique is utilized to derive the pressure in the aorta .

Upon bilateral application of the INEM – Transform to equation (9), the resulting expression is obtained:

$$E\left\{f'(t) + \frac{c}{k}f(t)\right\} = E\{cA\sin wt\}$$

Let $E\{f(t)\} = I(v)$,

Use above propriety and theorem we obtain

$$\left(q(v)\right)^{\frac{1}{n}} I(v) - p(v)f(0) + \frac{c}{k}I(v) = \frac{cAwp(v)}{\left(q(v)\right)^{\frac{2}{n}} + w^2}$$

By swapping out the initial conditions in the equation above, we get

$$\left(\left(q(v)\right)^{\frac{1}{n}} + \frac{c}{k}\right) I(v) = \frac{cAwp(v)}{\left(q(v)\right)^{\frac{2}{n}} + w^2}$$

$$I(v) = \frac{cAwp(v)}{\left(\left(q(v)\right)^{\frac{1}{n}} + \frac{c}{k}\right)\left(\left(q(v)\right)^{\frac{2}{n}} + w^2\right)}$$

$$I(v) = \frac{cAw}{\left(\frac{c}{k}\right)^2 + w^2}\frac{p(v)}{\left(\left(q(v)\right)^{\frac{1}{n}} + \frac{c}{k}\right)} + \frac{cAw\frac{c}{k}}{\left(\frac{c}{k}\right)^2 + w^2}\frac{p(v)}{\left(\left(q(v)\right)^{\frac{2}{n}} + w^2\right)} - \frac{cAw}{\left(\frac{c}{k}\right)^2 + w^2}\frac{p(v)\left(q(v)\right)^{\frac{1}{n}}}{\left(\left(q(v)\right)^{\frac{2}{n}} + w^2\right)}$$

Now applying I^{-1} of both sided of a bove equation we get

$$f(t) = \frac{cAw}{\left(\frac{c}{k}\right)^2 + w^2} I^{-1}\left\{\frac{p(v)}{\left(\left(q(v)\right)^{\frac{1}{n}} + \frac{c}{k}\right)}\right\} + \frac{cA\frac{c}{k}}{\left(\frac{c}{k}\right)^2 + w^2} I^{-1}\left\{\frac{wp(v)}{\left(\left(q(v)\right)^{\frac{2}{n}} + w^2\right)}\right\} - \frac{cAw}{\left(\frac{c}{k}\right)^2 + w^2} I^{-1}\left\{\frac{p(v)\left(q(v)\right)^{\frac{1}{n}}}{\left(\left(q(v)\right)^{\frac{2}{n}} + w^2\right)}\right\}$$

$$f(t) = \frac{cAw}{\left(\frac{c}{k}\right)^2 + w^2}e^{-\frac{c}{k}t} - \frac{cA\frac{c}{k}}{\left(\frac{c}{k}\right)^2 + w^2}\sin wt - \frac{cAw}{\left(\frac{c}{k}\right)^2 + w^2}\cos wt$$

V. Conclusion.

In this paper, transformations of different types of linear, exponential, and trigonometric functions were deduced, with basic and important properties to work as the linear property and higher-order derivatives using the transformation of newly defined integral transform "INEM – Transform" which contributed a successful role in solving the differential equations with initial values, the solution was found on two applications, the first on the concentration of glucose in the blood and the other on the aortic pressure of the heart, and in both applications efficient results were obtained with the INEM – Transform in this work.

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