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A Study on Integer Design of Exponential Solutions of Diophantine Equation $(X^4 - Y^4)^{\beta}(p^2 + q^2 + t^2) = m(r^2 + s^2 + u^2)(Z^2 - W^2)\alpha^{\beta}$ With $\alpha > 0, \beta > 1, and\ Y < X < W < Z$

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ABSTRACT:

This paper focused on a study to find integer design of solutions Diophantine Equation

$(X^4 - Y^4)^{\beta}(p^2 + q^2 + t^2) = m(r^2 + s^2 + u^2)(Z^2 - W^2)\alpha^{\beta}$ **With** $\alpha > 0, \beta > 1, Y < X < W < Z$

with Mathematical induction method for $\beta = 1,2,3,4, \ldots\ and\ so\ on.$ Diophantine equations of higher degrees, play a meaningful role in generating special elliptic curves that are crucial for cryptography and secure communications.

In this paper, I was focused given Diophantine equation with more than 12 unknowns.

$(X^4 - Y^4)^{\beta}(p^2 + q^2 + t^2) = m(r^2 + s^2 + u^2)(Z^2 - W^2)\alpha^{\beta}$ **With** $\alpha > 0, \beta > 1, Y < X < W < Z$

We know that integer design of solutions with the Pythagorean (3;3) tuples equation as follows

$p^2 + q^2 + t^2 = r^2 + s^2 + u^2$, which is having different sets of integer solutions is illustrated below $p = x^2yh$, $q = y^2xh$, $r = yh$, $s = xh$, $t = xy$, $u = xyzh$

where $x = bc$, $y = ca$, $h = ab$, $z = c^2$ with (a, b, c) is a Pythagorean triplet, which is satisfies $a^2 + b^2 = c^2$.

In particular for $\beta = 2$ is

$$y = k^n, x = k^{n+1}, m=1, \alpha = k^{4n} \text{ and } \begin{Bmatrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right), w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right), & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right), w = \left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4 - 1\ is\ odd \end{Bmatrix}.$$

for $\beta = 3$ *is*

$$y = k^n, x = k^{n+1}, m=k^4 - 1, \alpha = k^{4n} \text{ and } \begin{Bmatrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right), w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right), & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right), w = \left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4 - 1\ is\ odd \end{Bmatrix}$$

for $\beta = 4$ *is*

$$y = k^n, x = k^{n+1}, m=(k^4 - 1)^2, \alpha = k^{4n} \text{ and } \begin{Bmatrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right), w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right), & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right), w = \left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4 - 1\ is\ odd \end{Bmatrix}.$$

Hence generalized integer design of solutions **for** $\beta > 1$ *is*

$$y = k^n, x = k^{n+1}, m=(k^4 - 1)^{\beta-2}, \alpha = k^{4n}, \begin{Bmatrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right), w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right), & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right), w = \left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4 - 1\ is\ odd \end{Bmatrix}$$

KEYWORDS: Diophantine Equation, exponential, Pythagorean triplet, Integer design.

I. INTRODUCTION:

Diophantine equations with many unknowns, such as those exceeding nine variables, extend classical problems like Pythagorean triples into higher-degree forms relevant to number theory and cryptography. These equations generate integer solutions that underpin elliptic curves used in secure protocols, with mathematical induction proving patterns in solution sets. The provided abstract highlights Pythagorean (3,3) tuples, where solutions like (a, b, c) satisfying $a^2+b^2=c^2$ scale to multivariable cases involving parameters s, t, u, and z.

Role in Cryptography

Higher-degree Diophantine equations produce special elliptic curves essential for elliptic curve cryptography (ECC), which offers efficient key generation and secure communications due to the discrete logarithm problem's hardness. Integer solutions from these equations, verified via induction, form bases for curve parameters resistant to quantum attacks in post-quantum schemes. Pythagorean triples extend here as primitive blocks, generating tuples like (3k, 4k, 5k) that embed into larger systems for key spoofing or hash distribution

II. RESULTS & DISCUSSIONS:

In this paper, focused to find the general exponential integer solution of the general exponential integer solution of $(\boldsymbol{X^4-Y^4})^{\boldsymbol{\beta}}(\boldsymbol{p^2+q^2+t^2}) = \boldsymbol{m}(\boldsymbol{r^2+s^2+u^2})(\boldsymbol{Z^2-W^2})\boldsymbol{\alpha^{\beta}}$

With p is odd, $\boldsymbol{\alpha > 0, \beta > 1, X < Y < W < Z}$

LEMMA 1: Consider the Pythagorean (3;3) tuples equation as follows

$$p^2 + q^2 + t^2 = r^2 + s^2 + u^2$$

then different sets of integer solutions is illustrated below

$$p = x^2yh\,,\ q = y^2xh\,,\ r = yh,\ s = xh,\ \ t = xy,\ u = xyzh$$

where $x = bc$, $y = ca$, $h = ab$, $z = c^2$ with (a, b, c) is a Pythagorean triplet, which is satisfies $a^2 + b^2 = c^2$.

E.g.1: Choose the Pythagorean triplet (a, b, c) is (3, 4, 5), which follows

$x = bc = 20$, $y = ca = 15$, $h = ab = 12$, $z = c^2 = 25$

$p = x^2yh = 72000$, $q = y^2xh = 54000$, $r = yh = 180$, $s = xh = 240$, $t = xy = 300$,

$u = xyzh = 90000$

$p^2 + q^2 + t^2 = 8100090000$

$r^2 + s^2 + u^2 = 8100090000$. Hence $p^2 + q^2 + t^2 = r^2 + s^2 + u^2$.

Proportion 1: A Study on exponential integer solution of above Diophantine Equation at

$\boldsymbol{\beta = 2}$ **is** $(\boldsymbol{X^4 - Y^4})^{\boldsymbol{2}}(\boldsymbol{p^2 + q^2 + t^2}) = \boldsymbol{m}(\boldsymbol{r^2 + s^2 + u^2})(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha^2}$

Explanation:

From Lemma 1,

$$p^2 + q^2 + t^2 = r^2 + s^2 + u^2$$

then different sets of integer solutions is illustrated below

$$p = x^2yh\,,\ q = y^2xh\,,\ r = yh,\ s = xh,\ \ t = xy,\ u = xyzh$$

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where $x = bc$, $y = ca, h = ab$, z = c^2 with (a, b, c) is a Pythagorean triplet, which is satisfies $a^2 + b^2 = c^2$.

Now we can go to verify only $(\boldsymbol{X^4 + Y^4})^2 = \boldsymbol{m(Z^2 - W^2)\alpha^2}$

Let y = $k^n, x = k^{n+1}$,

Consider $(X^4 - Y^4)^2 = k^{8n}(k^4 - 1)^2$.

Let $\boldsymbol{\alpha}$ = $k^{4n}, m = 1$

Again consider $\boldsymbol{m(Z^2 - W^2)\alpha^2} = k^{8n}(\boldsymbol{Z^2 - W^2})$

It follows that $(\boldsymbol{X^4 - Y^4})^2 = \boldsymbol{m(Z^2 - W^2)\alpha^2}$ implies that $k^{8n}(k^4 - 1)^2 = k^{8n}(\boldsymbol{Z^2 - W^2})$

Solve for z, w, whenever $(k^4 - 1, z, w)$ is a Pythagorean Triplet.

From the References [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12] there is so many methods to generate Pythagorean triplet, now I chosen one of the technique of

if r is an even number, then (r, $\left(\frac{r}{2}\right)^2 - 1$, $\left(\frac{r}{2}\right)^2 + 1$) is a Pythagorean triplet.

If r is an odd number, then (r, $\frac{r^2-1}{2}$, $\frac{r^2+1}{2}$) is a Pythagorean triplet.

It implies that $(k^4 - 1, z, w)$ becomes a Pythagorean Triplet depending on $whether\ k^4 - 1$ is odd or even.

If $k^4 - 1$ is even, then ($k^4 - 1$, $\left(\frac{k^4-1}{2}\right)^2 - 1$, $\left(\frac{k^4-1}{2}\right)^2 + 1$) is a Pythagorean triplet

with $z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right), w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right)$ $and\ z^2 - w^2 = (k^4 - 1)^2$.

If $k^4 - 1$ is odd, then ($k^4 - 1$, $\frac{(k^4-1)^2-1}{2}$, $\frac{(k^4-1)^2+1}{2}$) is a Pythagorean triplet.

whenever $(k^4 - 1, w, z)$ becomes a Pythagorean Triplet with $z = \left(\frac{(k^4-1)^2+1}{2}\right), w = \left(\frac{(k^4-1)^2-1}{2}\right)$

Hence, **we obtain** $(\boldsymbol{X^4 + Y^4})^2(\boldsymbol{p^2 + q^2 + t^2}) = \boldsymbol{m(r^2 + s^2 + u^2)(Z^2 - W^2)\alpha^2}$ **having integer design of solution is** y = $k^n, x = k^{n+1}$,

m=1, $\alpha = k^{4n}$ and $\left\{\begin{matrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right), w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right), & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right), w = \left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4 - 1\ is\ odd \end{matrix}\right\}$, and

Proportion 2: : A Study on exponential integer solution of above Diophantine Equation at

$\boldsymbol{\beta = 3}$ **is** $(\boldsymbol{X^4 - Y^4})^3(\boldsymbol{p^2 + q^2 + t^2}) = \boldsymbol{m(r^2 + s^2 + u^2)(Z^2 - W^2)\alpha^3}$

Explanation: From Lemma 1,

$p^2 + q^2 + t^2 = r^2 + s^2 + u^2$

then different sets of integer solutions is illustrated below

$p = x^2yh$, $q = y^2xh$, $r = yh$, s= xh, $t = xy$, $u = xyzh$

where $x = bc$, $y = ca, h = ab$, z = c^2 with (a, b, c) is a Pythagorean triplet, which is satisfies $a^2 + b^2 = c^2$.

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Now we can go to verify only $(\boldsymbol{X^4 - Y^4})^3 = \boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^3$

Let y = $k^n, x = k^{n+1}$,

Consider $(X^4 - Y^4)^3 = k^{12n}(k^4 - 1)^3$.

Let $\boldsymbol{\alpha} = k^{4n}, m = k^4 - 1$

Again consider $\boldsymbol{C}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^3 = k^{12n}(1 + k^4)(\boldsymbol{Z^2 - W^2})$

It follows that $(\boldsymbol{X^4 + Y^4})^3 = \boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^3$ implies that $k^{12n}(k^4 - 1)^3 = k^{12n}(k^4 - 1)(\boldsymbol{Z^2 - W^2})$

Solve for z, w, whenever $(k^4 - 1, z, w)$ is a Pythagorean Triplet.

From the References [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12] there is so many methods to generate Pythagorean triplet, now I chosen one of the technique of

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If r is an odd number, then (r, $\frac{r^2-1}{2}$, $\frac{r^2+1}{2}$) is a Pythagorean triplet.

It implies that $(k^4 - 1, z, w)$ becomes a Pythagorean Triplet depending on $whether$ $k^4 - 1$ is odd or even.

If $k^4 - 1$ is even, then ($k^4 - 1$, $\left(\frac{k^4-1}{2}\right)^2 - 1$, $\left(\frac{k^4-1}{2}\right)^2 + 1$) is a Pythagorean triplet

with $z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right)$, $w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right)$ and $z^2 - w^2 = (k^4 - 1)^2$.

If $k^4 - 1$ is odd, then ($k^4 - 1$, $\frac{(k^4-1)^2-1}{2}$, $\frac{(k^4-1)^2+1}{2}$) is a Pythagorean triplet.

whenever $(k^4 - 1, w, z)$ becomes a Pythagorean Triplet with $z = \left(\frac{(k^4-1)^2+1}{2}\right)$, $w = \left(\frac{(k^4-1)^2-1}{2}\right)$

Hence, **we obtain $(\boldsymbol{X^4 - Y^4})^3 = \boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^3$ having integer design of solution is**

y = $k^n, x = k^{n+1}$,

m=$(1 + k^4), \alpha = k^{4n}$ and $\begin{Bmatrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right)n, w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right)n, & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right)n, w = \left(\frac{(k^4-1)^2-1}{2}\right)n, & if\ k^4 - 1\ is\ odd \end{Bmatrix}$

Verification:

Consider **LHS** $(\boldsymbol{X^4 - Y^4})^3 = (k^4 - 1)^3 k^{12n}$

Consider RHS $\boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^3 = (k^4 - 1)^3 k^{12n}$. **Hence LHS = $\boldsymbol{RHS}$.**

Proportion 3: A Study on exponential integer solution of above Diophantine Equation at

$\boldsymbol{\beta} = \mathbf{4}$ **is** $(\boldsymbol{X^4 - Y^4})^4 = \boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^4$

Explanation: From Lemma 1,

$p^2 + q^2 + t^2 = r^2 + s^2 + u^2$

then different sets of integer solutions is illustrated below

$p = x^2yh$, $q = y^2xh$, $r = yh$, $s = xh$, $t = xy$, $u = xyzh$

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where $x = bc$, $y = ca, h = ab$, z = c^2 with (a, b, c) is a Pythagorean triplet, which is satisfies $a^2 + b^2 = c^2$.

Now we can go to verify only $(\boldsymbol{X^4 - Y^4})^4 = \boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^4$

Let y = $k^n, x = k^{n+1}$,

Consider $(X^4 - Y^4)^4 = k^{16n}(k^4 - 1)^4$. Let $\boldsymbol{\alpha} = k^{4n}, m = (k^4 - 1)^2$

Again consider $\boldsymbol{C}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^4 = k^{16n}(k^4 - 1)^2(\boldsymbol{Z^2 - W^2})$

It follows that $(\boldsymbol{X^4 - Y^4})^4 = \boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^4$ implies that $k^{16n}(k^4 - 1)^4 = k^{16n}(k^4 - 1)^2(\boldsymbol{Z^2 - W^2})$

Solve for z, w, whenever $(k^4 - 1, z, w)$ is a Pythagorean Triplet.

From the References [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12] there is so many methods to generate Pythagorean triplet, now I chosen one of the technique of

if r is an even number, then (r, $\left(\frac{r}{2}\right)^2 - 1$, $\left(\frac{r}{2}\right)^2 + 1$) is a Pythagorean triplet.

If r is an odd number, then (r, $\frac{r^2-1}{2}$, $\frac{r^2+1}{2}$) is a Pythagorean triplet.

It implies that $(k^4 - 1, z, w)$ becomes a Pythagorean Triplet depending on *whether* $k^4 - 1$ is odd or even.

If $k^4 - 1$ **is even**, then ($k^4 - 1$, $\left(\frac{k^4-1}{2}\right)^2 - 1$, $\left(\frac{k^4-1}{2}\right)^2 + 1$) is a Pythagorean triplet

with $z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right), w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right)$ *and* $z^2 - w^2 = (k^4 - 1)^2$.

If $k^4 - 1$ **is odd**, then ($k^4 - 1$, $\frac{(k^4-1)^2-1}{2}$, $\frac{(k^4-1)^2+1}{2}$) is a Pythagorean triplet.

whenever $(k^4 - 1, w, z)$ becomes a Pythagorean Triplet with $z = \left(\frac{(k^4-1)^2+1}{2}\right), w = \left(\frac{(k^4-1)^2-1}{2}\right)$

Hence, **we obtain** $(\boldsymbol{X^4 - Y^4})^4 = \boldsymbol{m}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^4$ **having integer design of solution is**

y = $k^n, x = k^{n+1}$,

m=$(k^4 - 1)^2, \alpha = k^{4n}$ and $\begin{Bmatrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right)n, w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right)n, & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right)n, w = \left(\frac{(k^4-1)^2-1}{2}\right)n, & if\ k^4 - 1\ is\ odd \end{Bmatrix}$

Verification:

Consider **LHS** $(\boldsymbol{X^4 - Y^4})^4 = (k^4 - 1)^4 k^{16n}$

Consider RHS $\boldsymbol{C}(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^4 = (k^4 - 1)^4 k^{16n}$ **Hence LHS =** $\boldsymbol{RHS}$**.**

Main Result: Hence generalized integer design of solutions **for** $\boldsymbol{\beta > 1}$ *is*

y = $k^n, x = k^{n+1}$, m=$(k^4 - 1)^{\beta-2}, \alpha = k^{4n}$, $\begin{Bmatrix} z = \left(\left(\frac{k^4-1}{2}\right)^2 + 1\right)n, w = \left(\left(\frac{k^4-1}{2}\right)^2 - 1\right)n, & if\ k^4 - 1\ is\ even \\ z = \left(\frac{(k^4-1)^2+1}{2}\right)n, w = \left(\frac{(k^4-1)^2-1}{2}\right)n, & if\ k^4 - 1\ is\ odd \end{Bmatrix}$

III. CONCLUSION

In this paper, I was focused given Diophantine equation with more than 5 unknowns.

$(\boldsymbol{X^4 - Y^4})^{\boldsymbol{\beta}}(\boldsymbol{p^2 + q^2 + t^2}) = \boldsymbol{m}(\boldsymbol{r^2 + s^2 + u^2})(\boldsymbol{Z^2 - W^2})\boldsymbol{\alpha}^{\boldsymbol{\beta}}$ **With** $\boldsymbol{\alpha > 0, \beta > 1, X < Y < W < Z}$

Having integer design of solutions with

$$p^2+q^2+t^2=r^2+s^2+u^2$$

then different sets of integer solutions is illustrated below

$$p=x^2yh\ ,\ q=y^2xh\ ,\ r=yh,\ s=xh,\ \ t=xy,\ u=xyzh$$

where $x=bc$, $y=ca$, $h=ab$, $z=c^2$ with (a, b, c) is a Pythagorean triplet, which is satisfies $a^2+b^2=c^2$.

In particular for $\boldsymbol{\beta}=\mathbf{2}$ is

$$y=k^n, x=k^{n+1}, m=1, \alpha=k^{4n} \text{ and } \begin{Bmatrix} z=\left(\left(\frac{k^4-1}{2}\right)^2+1\right), w=\left(\left(\frac{k^4-1}{2}\right)^2-1\right), & if\ k^4-1\ is\ even \\ z=\left(\frac{(k^4-1)^2+1}{2}\right), w=\left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4-1\ is\ odd \end{Bmatrix}.$$

for $\boldsymbol{\beta}=\mathbf{3}$ *is*

$$y=k^n, x=k^{n+1}, m=k^4-1, \alpha=k^{4n} \text{ and } \begin{Bmatrix} z=\left(\left(\frac{k^4-1}{2}\right)^2+1\right), w=\left(\left(\frac{k^4-1}{2}\right)^2-1\right), & if\ k^4-1\ is\ even \\ z=\left(\frac{(k^4-1)^2+1}{2}\right), w=\left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4-1\ is\ odd \end{Bmatrix}$$

for $\boldsymbol{\beta}=\mathbf{4}$ *is*

$y=k^n, x=k^{n+1}$, m=$(k^4-1)^2$,

$$\alpha=k^{4n} \text{ and } \begin{Bmatrix} z=\left(\left(\frac{k^4-1}{2}\right)^2+1\right), w=\left(\left(\frac{k^4-1}{2}\right)^2-1\right), & if\ k^4-1\ is\ even \\ z=\left(\frac{(k^4-1)^2+1}{2}\right), w=\left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4-1\ is\ odd \end{Bmatrix}.$$

Hence generalized integer design of solutions **for $\boldsymbol{\beta}>\mathbf{1}$** *is*

$$y=k^n, x=k^{n+1}, m=(k^4-1)^{\beta-2}, \alpha=k^{4n}\ , \begin{Bmatrix} z=\left(\left(\frac{k^4-1}{2}\right)^2+1\right), w=\left(\left(\frac{k^4-1}{2}\right)^2-1\right), & if\ k^4-1\ is\ even \\ z=\left(\frac{(k^4-1)^2+1}{2}\right), w=\left(\frac{(k^4-1)^2-1}{2}\right), & if\ k^4-1\ is\ odd \end{Bmatrix}$$

Future Work: With using of quadratic Diophantine equation, to derive the integer design of solutions of various higher degree and higher order inhomogeneous equations with 10 or more unknown parameters, which are more useful for cryptographic secure key generation.

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