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A Study on Integer Design of Exponential Solutions of Diophantine Equation $(X^4+Y^4)^\beta(p^6+q^6+3r^2)=C(s^6)(Z^2-W^2)\alpha^\beta$ With $\alpha>0,\beta>1, and\ X<Y<W<Z$

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ABSTRACT:

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

$(X^4+Y^4)^\beta(p^6+q^6+3r^2)=C(s^6)(Z^2-W^2)\alpha^\beta$ **With** $\alpha>0,\beta>1,X<Y<W<Z$

with Mathematical induction method for $\beta=1,2,3,4,\dots$ *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 9 unknowns.

$(X^4+Y^4)^\beta(p^6+q^6+3r^2)=C(s^6)(Z^2-W^2)\alpha^\beta$ **With** $\alpha>0,\beta>1,X<Y<W<Z$

Having integer design of solutions with

Case 1: If p is an odd, then different sets of integer solutions is illustrated below

$q=\frac{p^2-1}{2}$, $r=\frac{p(p^4-1)}{4}$ and $s=\frac{p^2+1}{2}$.

Case 2: If p is an even integer, then different sets of integer solutions is illustrated below

$q=\left(\frac{p}{2}\right)^2-1,\ r=p\left(\left(\frac{p}{2}\right)^4-1\right)$ and $s=\left(\frac{p}{2}\right)^2+1$

In particular for $\beta=2$ is

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

for $\beta=3$ *is*

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

for $\beta=4$ *is*

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

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

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

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

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

I. INTRODUCTION

Diophantine equations—polynomial equations with integer solutions—are a central topic in number theory. Among their many variants, **exponential Diophantine equations** involve terms where variables appear as exponents. Finding integer solutions to such equations is notably complex and has implications in mathematics, cryptography, and several scientific fields. Historical Context and Theoretical Background

Classical Diophantine Equations: Traditionally, research started with linear and polynomial forms, such as the well-known cases of Pythagorean triples.

Exponential Generalization: The study of exponential forms expanded from these roots, posing questions that often lack general solution methods and in some cases are proven to be undecidable.

II. RESULTS & DISCUSSIONS

In this paper, focused to find the general exponential integer solution of the general exponential integer solution of $(\boldsymbol{X^4 + Y^4})^{\boldsymbol{\beta}}(\boldsymbol{p^6 + q^6 + 3r^2}) = \boldsymbol{C(s^6)(Z^2 - W^2)\alpha^\beta}$ **With p is odd,** $\boldsymbol{\alpha > 0, \beta > 1, X < Y < W < Z}$

LEMMA 1: Consider higher degree Diophantine equation $p^6 + q^6 + 3r^2 = s^6$

Having two types of solutions

Case 1: If p is an odd, then different sets of integer solutions is illustrated below

$q = \frac{p^2-1}{2}$, $r = \frac{p(p^4-1)}{4}$ and $s = \frac{p^2+1}{2}$.

Verification: Let p =3, then q = 4, r = 60, s = 5.

Consider $p^6 + q^6 + 3r^2 = 729 + 4096 + 3(3600) = 15625 = 5^6 = s^6$

Case 2: If p is an even integer, then different sets of integer solutions is illustrated below

$q = \left(\frac{p}{2}\right)^2 - 1,\ r = p\left(\left(\frac{p}{2}\right)^4 - 1\right)$ and $s = \left(\frac{p}{2}\right)^2 + 1$

Verification: Let p = 4, then q = 3, r = 60, s = 5

Consider $p^6 + q^6 + 3r^2 = 4096 + 729 + 3(3600) = 15625 = 5^6 = s^6$

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

$\boldsymbol{\beta = 2}$ **is** $(\boldsymbol{X^4 + Y^4})^2(\boldsymbol{p^6 + q^6 + 3r^2}) = \boldsymbol{C(s^6)(Z^2 - W^2)\alpha^2}$

Explanation:

From Lemma 1, $p^6+q^6+3r^2=s^6$ is verified for different set of integer design of solutions for each p is either even or odd.

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

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

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

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

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

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

Solve for z, w, whenever $(1+k^4, z, w)$ 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 $(1+k^4, z, w)$ becomes a Pythagorean Triplet depending on $whether$ $1+k^4$ is odd or even.

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

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

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

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

Hence, **we obtain $(\boldsymbol{X^4}+\boldsymbol{Y^4})^2(\boldsymbol{p^6}+\boldsymbol{q^6}+\boldsymbol{3r^2})=\boldsymbol{C}(\boldsymbol{s^6})(\boldsymbol{Z^2}-\boldsymbol{W^2})\boldsymbol{\alpha^2}$ having integer design of solution is** x = $k^n, y=k^{n+1}$,

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

Case 1: If p is an odd, then different sets of integer solutions is illustrated below

$q=\frac{p^2-1}{2}$, $r=\frac{p(p^4-1)}{4}$ and $s=\frac{p^2+1}{2}$.

Case 2: If p is an even integer, then different sets of integer solutions is illustrated below

$q=\left(\frac{p}{2}\right)^2-1$, $r=p\left(\left(\frac{p}{2}\right)^4-1\right)$ and $s=\left(\frac{p}{2}\right)^2+1$

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

$\boldsymbol{\beta = 3}$ **is** $\boldsymbol{(X^4+Y^4)^3(p^6+q^6+3r^2) = C(s^6)(Z^2-W^2)\alpha^3}$

Explanation: From Lemma 1, $p^6+q^6+3r^2 = s^6$ is verified for different set of integer design of solutions for each p is either even or odd.

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

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

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

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

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

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

Solve for z, w, whenever $(1+k^4, z, w)$ 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 $(1+k^4, z, w)$ becomes a Pythagorean Triplet depending on *whether* $1+k^4$ is odd or even.

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

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

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

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

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

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

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

Verification:

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

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

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

$\beta = 4$ **is** $(X^4 + Y^4)^4 = C(Z^2 - W^2)\alpha^4$

Explanation: From Lemma 1, $p^6 + q^6 + 3r^2 = s^6$ is verified for different set of integer design of solutions for each p is either even or odd.

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

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

Consider $(X^4 + Y^4)^4 = k^{16n}(1 + k^4)^4$.

Let $\alpha = k^{4n}, c = (1 + k^4)^2$

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

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

Solve for z, w, whenever $(1 + k^4, z, w)$ 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 $(1 + k^4, z, w)$ becomes a Pythagorean Triplet depending on $whether$ $1 + k^4$ is odd or even.

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

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

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

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

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

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

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

Verification:

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

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

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

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

III. CONCLUSION

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

$(\boldsymbol{X^4+Y^4})^{\boldsymbol{\beta}}(\boldsymbol{p^6+q^6+3r^2}) = \boldsymbol{C}(\boldsymbol{s^6})(\boldsymbol{Z^2-W^2})\boldsymbol{\alpha^\beta}$ **With** $\boldsymbol{\alpha > 0, \beta > 1, X < Y < W < Z}$

Having integer design of solutions with

Case 1: If p is an odd, then different sets of integer solutions is illustrated below

$q = \frac{p^2-1}{2},\ r = \frac{p(p^4-1)}{4}$ and $s = \frac{p^2+1}{2}$.

Case 2: If p is an even integer, then different sets of integer solutions is illustrated below

$q = \left(\frac{p}{2}\right)^2 - 1,\ r = p\left(\left(\frac{p}{2}\right)^4 - 1\right)$ and $s = \left(\frac{p}{2}\right)^2 + 1$

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

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

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

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

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

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

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

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

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

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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