International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

A Study of Some Curvature Tensor on Trans-Sasakian Manifolds Admitting the Quarter-Symmetric Non Metric Connection

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Abstract: ***The objective of present paper is to study the some curvature properties related to the projective curvature tensor, conformal curvature tensor, concircular curvature tensor, conharmonic curvature and quasi-conformal tensor of quarter symmetric non metric connection in Trans-Sasakian manifolds. In this paper we also studied the some results related to the projective ricci tensor and pseudo projective curvature tensor.***

Keywords: Trans-Sasakian manifolds, Quarter-symmetric, Curvature tensor, Pseudo-projective, Projective ricci tensor.

1. Introduction

In 1975, Golab[6] introduced the quarter-symmetric linear connection on a differentiable manifold. Let T be the Torsion tensor defined as

$$T(X,Y)=D_XY-D_YX-[X,Y] \qquad (1.1)$$

A linear connection D in an n dimensional manifold is said to be quarter-symmetric connection if the Torsion tensor T is satisfies the condition:

$$T(X,Y)=\eta(X)\phi Y-\eta(Y)\phi X \qquad (1.2)$$

Where η is1-form and ϕ is a tensor of type (1, 1).

The quarter-symmetric linear connection D satisfies the condition $D_Xg\neq 0$ for all $X\in TM$, then D is said to be quarter-symmetric non metric connection otherwise metric connection. Where TM is lie algebra of vector field of the manifold M^n. Quarter symmetric non metric connection is studied by Patra and Bhattacharya[8] and Singh and Pandey[12] and others.

Further if we replace $\phi X=X$ and $\phi Y=Y$, then the quarter symmetric linear connection reduces to the semi-symmetric connection[5].

J.A. Obina[7] 1985, introduced a new class of almost contact manifold namely Trans-Sasakian manifolds which includes the Sasakian, Kenmostu and Cosymplectic structures. After that many other authors like Bagewadi and Girish[1], Bagewadi and Venkatesha[2], Prasad and Srivastava[9], Tarafdar and Bhattacharya[13] and Yano and Kon [14] studied it and get some results.

This paper is organized as follows:

After the introduction, in section2, we have the brief introduction of Trans–Sasakian manifold admitting the quarter-symmetric non metric connection. In section 3 we obtained some basic results. In section4, we study some properties of curvature tensor like projective curvature tensor, conformal curvature tensor, concircular curvature tensor, conharmonic curvature tensor, quasi conformal curvature and pseudo projective curvature tensor. At last we study the some results on projective ricci tensor.

2. Preliminaries

Let M be an almost contact metric manifold of odd dimension n with an almost contact structure (ϕ,ξ,η,g), where ϕ is $(1,1)$ tensor field, ξ is contravariant vector field, η is a 1-form and g is an associated Riemannian metric such that[4]

$$\phi^2=-I+\eta\otimes\xi \qquad (2.1)$$

$$\eta(\xi)=1,\ \ \phi\xi=0,\ \ \eta\phi=0 \qquad (2.2)$$

$$g(\phi X,\phi Y)=g(X,Y)-\eta(X)\eta(Y) \qquad (2.3)$$

$$g(X,\phi Y)=-g(\phi X,Y) \qquad (2.4)$$

$$g(X,\xi)=\eta(X) \qquad (2.5)$$

An almost contact metric manifold M (ϕ,ξ,η,g) is said to be a Trans-Sasakian manifold if $(M\times R,J,G)$ belong to class W_4 of the Hermitian manifolds, where *J* is the almost complex structure on $M\times R$ defined by[7]

$$J\left(Z,f\frac{d}{dt}\right)=\left(\phi Z-f\xi,\eta(Z)\frac{d}{dt}\right)$$

For any vector field *Z* on *M* and the smooth function *f* on $M\times R$ and *G* is Hermitian metric on the product $M\times R$. This may be expressed by the condition [7]

$$(\nabla_X\phi)Y=$$
$$\alpha\{g(X,Y)\xi-\eta(Y)X\}+\beta\{g(\phi X,Y)\xi-\eta(Y)\phi X\} \qquad (2.6)$$

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for some smooth function α and β on M, then we say Trans-Sasakian structure is of type (α,β).

On a Trans-Sasakian manifold, it can be shown that [10]

$$\nabla_X \xi = -\alpha\phi X + \beta(X - \eta(X)\xi) \tag{2.7}$$

$$(\nabla_X \eta)Y = -\alpha g(\phi X, Y) + \beta g(\phi X, \phi Y) \tag{2.8}$$

$$\Phi(X,Y) = g(\phi X, Y) \tag{2.9}$$

Where Φ is fundamental 2-form.

$$S(X,\xi) = 2n(\alpha^2 - \beta^2 - \xi\beta)\eta(X) \tag{2.10}$$

$$S(\phi X, \phi Y) = S(X,Y) - 2n(\alpha^2 - \beta^2 - \xi\beta)\eta(X)\eta(Y) \tag{2.11}$$

In a Trans-Sasakian manifold the curvature tensor [9] is defined as

$$\begin{aligned} R(X,Y)\xi = {} & (\alpha^2 - \beta^2)[\eta(Y)X - \eta(X)Y] + \\ & 2\alpha\beta[\eta(Y)\phi X - \eta(X)\phi Y] + \\ & (Y\alpha)\phi X - (X\alpha)\phi Y - (Y\alpha)\phi X \\ & + (Y\beta)\phi^2 X - (X\beta)\phi^2 Y \end{aligned} \tag{2.12}$$

$$R(\xi, X)\xi = (\alpha^2 - \beta^2 - \xi\beta)[\eta(X)\xi - X] \tag{2.13}$$

Now for the quarter-symmetric non metric connection D of the Trans-Sasakian manifold is satisfied the following conditions [8].

$$(D_X g)(Y,Z) = -\{\eta(Y)g(\phi X, Z) + \eta(Z)g(\phi X, Y)\} \tag{2.14}$$

$$D_X Y = \nabla_X Y + \eta(Y)\phi X \tag{2.15}$$

$$\begin{aligned} \bar{R}(X,Y)Z = {} & R(X,Y)Z + 2\beta\eta(Z)g(\phi X, Y)\xi \\ & + \alpha[\eta(X)Y - \eta(Y)X]\eta(Z) + \\ & \alpha\{g(\phi Y, Z)\phi X - g(\phi X, Z)\phi Y\} \\ & + \beta\{g(X,Z)\phi Y - g(Y,Z)\phi X\} \end{aligned} \tag{2.16}$$

$$\begin{aligned} \bar{S}(X,Y) = {} & S(X,Y) - (n-1)\alpha\eta(X)\eta(Y) \\ & + \alpha g(\phi X, \phi Y) + \beta(\phi Y, X) \end{aligned} \tag{2.17}$$

$$\bar{r} = r \tag{2.18}$$

We know that the Trans-Sasakian structure of type $(0,0)$, $(0,\beta)$ and $(\alpha,0)$ are called Cosympletic, β-Kenmostu and the α-Sasakian manifold respectively.

3. Some Results and Discussion

We note that

$$\bar{K}(X,Y,Z,U) = g(\bar{R}(X,Y)Z,U) \tag{3.1}$$

$$K(X,Y,Z,U) = g(R(X,Y)Z,U) \tag{3.2}$$

Theorem1: In the quarter-symmetric non metric connection of Trans-Sasakian manifold, we have the following relations:

$$\bar{K}(X,Y,Z,U) + \bar{K}(Y,X,Z,U) = 0 \tag{3.3}$$

$$\begin{aligned} & \bar{K}(X,Y,Z,U) - \bar{K}(Z,U,X,Y) = \\ & \alpha[\eta(X)\eta(U)g(Z,Y) - \eta(Y)\eta(Z)g(X,U)] \\ & + \beta[g(X,U)g(\phi Z,Y) - g(Y,Z)g(\phi X,U)] \\ & + 2\beta\begin{bmatrix}\eta(Z)\eta(U)g(\phi X,Y) - \\ \eta(X)\eta(Y)g(\phi Z,U) \\ + g(X,Z)g(\phi U,Y)\end{bmatrix} \end{aligned} \tag{3.4}$$

Proof. From (2.16) and (3.1), we have

$$\begin{aligned} & \bar{K}(X,Y,Z,U) = \\ & K(X,Y,Z,U) + 2\beta\eta(Z)\eta(U)g(\phi Y, X) \\ & \alpha\eta(Z)\{\eta(X)g(Y,U) - \eta(Y)g(X,U)\} + \\ & \alpha\{g(\phi X, Z)g(\phi Y, U) - g(\phi Y, Z)g(\phi X, U)\} \\ & + \beta\{g(X,Z)g(\phi Y,U) - g(Y,Z)g(\phi X,U)\} \end{aligned} \tag{3.5}$$

Now interchanging X and Y in (3.5) and using the equation $K(X,Y,Z,U) + K(Y,X,Z,U) = 0$,
We obtain (3.3).

Similarly from (2.16), (3.5) and the equation $K(X,Y,Z,U) = K(Z,U,X,Y)$,
we have (3.4).

Theorem2: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D. Then for all X, Y, Z, $\xi \in TM$, we have

$$\begin{aligned} & \bar{R}(\xi, X)\xi = \\ & (\alpha^2 - \beta^2 - \xi\beta - \alpha)(\eta(X)\xi - X) \end{aligned} \tag{3.6}$$

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$$\begin{aligned}&\bar{R}(X,Y)\xi = \\ &(\alpha^2-\beta^2-\alpha)[\eta(Y)X-\eta(X)Y] \\ &+\beta(2\alpha-1)[\eta(Y)\phi X-\eta(X)\phi Y] \\ &+(Y\alpha)\phi X-(X\alpha)\phi Y+(Y\beta)\phi^2 X \\ &-(X\beta)\phi^2 Y+2\beta g(\phi X,Y)\xi\end{aligned} \tag{3.7}$$

$$\bar{S}(X,\xi)=[\alpha(2-n)+\beta]\eta(X) \tag{3.8}$$

$$\bar{S}(\phi X,\phi Y)=2\alpha g(X,Y) \tag{3.9}$$

Proof. By using (2.13) and (2.16), we get (3.6).
Again from (2.12) and (2.16), we obtain the result (3.7).
Similarly from (2.10) and (2.17), we have (3.8).
At last by using (2.11) and (2.17), we get (3.9).

4. Some Curvature Tensor

Definition.4.1: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D. The projective curvature tensor of M^n with respect to quarter-symmetric non metric connection D is defined by

$$\begin{aligned}&\bar{P}(X,Y)Z = \\ &\bar{R}(X,Y)Z-\frac{1}{(n-1)}[\bar{S}(Y,Z)X-\bar{S}(X,Z)Y]\end{aligned} \tag{4.1}$$

From (2.16) and (2.17), we obtain

$$\begin{aligned}&\bar{P}(X,Y)Z = \\ &P(X,Y)Z+2\beta\eta(Z)g(\phi X,Y)\xi+ \\ &\alpha\{g(\phi Y,Z)\phi X-g(\phi X,Z)\phi Y\}+ \\ &\beta\{g(X,Z)\phi Y-g(Y,Z)\phi X\} \\ &-\frac{1}{(n-1)}\begin{bmatrix}\alpha g(Y,Z)X-\alpha\eta(Y)\eta(Z)X \\ -\alpha g(X,Z)Y-\alpha\eta(X)\eta(Z)Y\end{bmatrix} \\ &-\frac{1}{(n-1)}[\beta g(\phi X,Z)Y-\beta g(\phi Y,Z)X]\end{aligned} \tag{4.2}$$

Again from (4.2), we get

$$\bar{P}(X,Y)Z+\bar{P}(Y,X)Z=0 \tag{4.3}$$

Hence we can state the following theorem:

Theorem3: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D, then the projective curvature tensor of M^n is skew-symmetric with respect to quarter-symmetric non metric connection D is skew-symmetric in X and Y.

Definition 4.2: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D. The conformal curvature tensor of M^n with respect to quarter-symmetric non metric connection D is defined by

$$\begin{aligned}&\bar{C}(X,Y,Z,U) = \\ &\bar{K}(X,Y,Z,U)- \\ &\frac{1}{(n-1)}\begin{bmatrix}g(Y,Z)\bar{S}(X,U)-g(X,Z)\bar{S}(Y,U)+ \\ g(X,U)\bar{S}(Y,Z)-g(Y,U)\bar{S}(X,Z)\end{bmatrix}+ \\ &\frac{\bar{r}}{(n-1)(n-2)}[g(Y,Z)g(X,U)-g(X,Z)g(Y,U)]\end{aligned} \tag{4.4}$$

From (2.16), (2.17), (3.1) and (4.4), we get

$$\begin{aligned}&\bar{C}(X,Y,Z,U) = \\ &g(R(X,Y)Z,U)+2\beta\eta(Z)\eta(U)g(\phi X,Y) \\ &+\alpha[\eta(X)g(Y,U)-\eta(Y)g(X,U)]\eta(Z) \\ &+\alpha[g(\phi Y,Z)g(\phi X,U)-g(\phi X,Z)g(\phi Y,U)] \\ &+\beta[g(X,Z)g(\phi Y,U)-g(Y,Z)g(\phi X,U)]- \\ &\frac{1}{(n-2)}\begin{bmatrix}g(Y,Z)\bar{S}(X,U)-g(X,Z)\bar{S}(Y,U)+ \\ g(X,U)\bar{S}(Y,Z)-g(Y,U)\bar{S}(X,Z)\end{bmatrix}+ \\ &\frac{\bar{r}}{(n-1)(n-2)}[g(Y,Z)g(X,U)-g(X,Z)g(Y,U)]\end{aligned} \tag{4.5}$$

Now from (4.5), we get

$$\bar{C}(X,Y,Z,U)+\bar{C}(Y,X,Z,U)=0 \tag{4.6}$$

Hence we can state the following theorem:

Theorem4: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D, then the conformal curvature tensor of M^n is skew-symmetric with respect to quarter-symmetric non metric connection D.

Definition.4.3: Let M be an n dimensional Trans-Sasakian manifold with the Riemannian connection ∇. The concircular curvature tensor of M with respect to Riemannian connection ∇ is defined by

$$\begin{aligned}&Z(X,Y)U = \\ &R(X,Y)U-\frac{r}{n(n-1)}[g(Y,U)X-g(X,U)Y]\end{aligned} \tag{4.7}$$

Definition.4.4: Let M^n be an n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D. The concircular curvature tensor of M^n with respect to quarter-symmetric non metric connection D is defined by

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$$\bar{Z}(X,Y)U = \bar{R}(X,Y)U - \frac{\bar{r}}{n(n-1)}[g(Y,U)X - g(X,U)Y] \quad (4.8)$$

From (2.16), (2.18) and (4.8), we get

$$\begin{aligned}\bar{Z}(X,Y)U &= Z(X,Y)U + 2\beta\eta(U)g(\phi X,Y)\xi \\ &+ \alpha[\eta(X)Y - \eta(Y)X]\eta(U) + \\ &\alpha[g(\phi Y,U)\phi X - g(\phi X,U)\phi Y] \\ &+ \beta[g(X,U)\phi Y - g(Y,U)\phi X]\end{aligned} \quad (4.9)$$

If $\alpha = 0$ and $\beta = 0$, then (4.9) give the following theorem:

Colloary5: The concircular curvature tensor of cosympletic manifold with respect to Riemannian connection is equal to the concircular curvature tensor of cosympletic manifold admitting the quarter-symmetric non metric connection.

$$Z(X,Y)U = \bar{Z}(X,Y)U \quad (4.10)$$

Definition.4.5: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D, then conharmonic curvature tensor of M^n with respect to quarter-symmetric non metric connection D is defined by

$$\begin{aligned}\bar{V}(X,Y,Z,U) &= \\ \bar{K}(X,Y,Z,U) &- \\ \frac{1}{(n-2)}&\begin{bmatrix}\bar{S}(Y,Z)g(X,U) - \bar{S}(X,Z)g(Y,U) + \\ \bar{S}(X,U)g(Y,Z) - \bar{S}(Y,U)g(X,Z)\end{bmatrix}\end{aligned} \quad (4.11)$$

If $\bar{S} = 0$, (4.11) gives

$$\bar{V}(X,Y,Z,U) = \bar{K}(X,Y,Z,U) \quad (4.12)$$

Hence we can state the following theorem:

Theorem6: If in an odd n- dimensional Trans-Sasakian manifold the ricci tensor of a quarter-symmetric non metric connection D vanishes, then the curvature tensor of M^n with respect to quarter-symmetric non metric connection D is equal to the con-harmonic curvature tensor of quarter-symmetric non metric manifold.

Definition.4.6: Let M^n be an n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D. The quasi conformal curvature tensor of M^n with respect to quarter-symmetric non metric connection D is defined by

$$\begin{aligned}\hat{\bar{C}}(X,Y,Z,U) &= \\ ag(\bar{R}(X,Y)Z,U) &+ \\ b\begin{bmatrix}\bar{S}(Y,Z)g(X,U) - \bar{S}(X,Z)g(Y,U) \\ + g(Y,Z)S(X,U) - g(X,Z)S(Y,U)\end{bmatrix} &- \\ \frac{r}{n}\left[\frac{a}{(n-1)} + 2b\right]&[g(Y,Z)g(X,U) - g(X,Z)g(Y,U)]\end{aligned} \quad (4.13)$$

Where a and b are constant such that $a \neq 0, b \neq 0$.

If $a = 1, b = \frac{1}{(n-1)}$ then quasi conformal curvature tensor reduces to conformal curvature tensor.

Now using (2.16), (2.17), (2.18) and (4.13) we get

$$\begin{aligned}\hat{\bar{C}}(X,Y,Z,U) &= \\ a&\begin{bmatrix}K(X,Y,Z,U) + 2\beta\eta(Z)\eta(U)g(\phi X,Y) \\ + \alpha\{\eta(X)g(Y,U) - \eta(Y)g(X,U)\}\eta(Z) \\ + \alpha\{g(\phi Y,Z)g(\phi X,U) - g(\phi X,Z)g(\phi Y,U)\} \\ + \beta\{g(X,Z)g(\phi Y,U) - g(Y,Z)g(\phi X,U)\}\end{bmatrix} \\ + b&\begin{bmatrix}S(Y,Z)g(X,U) - (n-1)\alpha\eta(Y)\eta(Z)g(X,U) \\ + \alpha g(\phi Y,\phi Z)g(X,U) + \beta g(\phi Y,Z)g(X,U) \\ - S(X,Z)g(Y,U) + (n-1)\alpha\eta(X)\eta(Z)g(Y,U) \\ - \alpha g(\phi X,\phi Z)g(Y,U) - \beta g(\phi X,Z)g(Y,U) \\ + g(Y,Z)S(X,U) - (n-1)\alpha\eta(X)\eta(U)g(Y,Z) \\ + \alpha g(\phi Y,\phi U)g(Y,Z) + \beta g(\phi X,U)g(Y,Z) \\ - S(Y,U)g(X,Z) + (n-1)\alpha\eta(Y)\eta(U)g(X,Z) \\ - \alpha g(\phi Y,\phi U)g(X,Z) - \beta g(\phi Y,U)g(X,Z)\end{bmatrix} \\ -\frac{r}{n}&\left[\frac{a}{(n-1)} + 2b\right][g(Y,Z)g(X,U) - g(X,Z)g(Y,U)]\end{aligned} \quad (4.14)$$

Now interchanging X and Y in (4.14), we have

$$\hat{\bar{C}}(X,Y,Z,U) + \hat{\bar{C}}(Y,X,Z,U) = 0 \quad (4.15)$$

Hence we state:

Theorem7: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D, then the quasi conformal curvature tensor of M^n is skew-symmetric with respect to quarter-symmetric non metric connection D in X and Y.

Definition.4.7: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D, then pseudo projective curvature tensor of M^n with respect to quarter-symmetric non metric connection D is defined by

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$$\bar{\tilde{P}}(X,Y)Z = aR(X,Y)Z + b[S(Y,Z)X - S(X,Z)Y] - \frac{r}{n}\left\{\frac{a}{(n-1)} + b\right\}[g(Y,Z)X - g(X,Z)Y] \quad (4.16)$$

Where a and b are constant such that $a, b \neq 0$

By using (2.16), (2.17), (2.18) and (4.16), we get

$$\begin{aligned}\bar{\tilde{P}}(X,Y)Z = &\tilde{P}(X,Y)Z + 2a\beta\eta(Z)g(\phi X,Y)\xi \\ &+ a\alpha[\eta(X)Y - \eta(Y)X]\eta(Z) + \\ &+ a\alpha[g(\phi Y,Z)\phi X - g(\phi X,Z)\phi Y] \\ &+ b\beta[g(\phi Z,Y)X + g(\phi Z,X)Y] \\ &+ 2b\alpha(n-1)[\eta(X)Y - \eta(Y)X]\eta(Z) \\ &+ b\alpha g(Y,Z)X\end{aligned} \quad (4.17)$$

Now from (4.17), we have

$$\bar{\tilde{P}}(X,Y)Z + \bar{\tilde{P}}(Y,X)Z = 0 \quad (4.18)$$

Hence we can state:

Theorem8: The pseudo projective curvature is skew-symmetric for an odd *n* dimensional Trans-Sasakian manifold with the quarter symmetric non metric connection D.

5. Projective RICCI Tensor

Definition.5.1: Let M^n be an odd n dimensional Trans-Sasakian manifold with the quarter-symmetric non metric connection D. The projective ricci tensor tensor of M^n with respect to quarter-symmetric non metric connection D is defined by

$$\bar{\hat{P}}(X,Y) = \frac{n}{(n-1)}\bar{S}(X,Y) - \frac{\bar{r}}{(n-1)}g(X,Y) \quad (5.1)$$

From (2.17), (2.18) and (5.1), we have

$$\bar{\hat{P}}(X,Y) = \frac{n}{(n-1)}[\alpha g(X,Y) + \beta g(\phi Y,X) - n\alpha\eta(X)\eta(Y)] \quad (5.2)$$

From (5.2), we get

$$\bar{\hat{P}}(X,Y) + \bar{\hat{P}}(Y,X) = \frac{n\alpha}{n-1}[g(X,Y) - n\eta(X)\eta(Y)] \quad (5.3)$$

If $\alpha = 0$ in (5.3), we can state

Corollary9: Let M^n be β-Kenmostu manifold admitting the quarter-symmetric non metric connection D, then the projective ricci tensor of M^n is skew-symmetric.

Again from (5.2), we get

$$\bar{\hat{P}}(X,Y) - \bar{\hat{P}}(Y,X) = \frac{2n\beta}{(n-1)}g(\phi Y,X) \quad (5.4)$$

If $\beta = 0$, then we can get

Corollary10: Let M^n be α-Sasakian manifold admitting the quarter-symmetric non metric connection D, then the projective ricci tensor of M^n is symmetric.

Now from (5.1), we have

$$\bar{\hat{P}}(X,Y) + \bar{\hat{P}}(Y,X) = \frac{n}{(n-1)}\left[\begin{array}{l}S(X,Y) - 2n\alpha\eta(X)\eta(Y) + \\ S(Y,X) + 2\alpha g(X,Y) - \frac{2n}{n}g(X,Y)\end{array}\right] \quad (5.5)$$

If $\bar{\hat{P}}(X,Y)$ is skew-symmetric then L.H.S of (5.5) is vanishes and

$$S(X,Y) = n\alpha\eta(X)\eta(Y) - \left[\alpha - \frac{r}{n}\right]g(X,Y) \quad (5.6)$$

Hence we can state:

Theorem11: An odd *n* dimensional Trans-Sasakian manifold admitting the quarter-symmetric non metric connection becomes the Einstein manifold if the projective ricci tensor is skew- symmetric.

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