

On $(r^*g^*)^*$ Closed Sets in Topological Spaces

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Abstract: *The aim of this paper is to introduce a new class of sets namely $(r^*g^*)^*$ closed sets in topological spaces. This class was obtained by generalizing closed sets via r^*g^* open sets which was introduced by N.Meenakumari and T.Indira[16]. This new class falls strictly between the class of closed sets and rg closed sets.*

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1. Introduction

In 1970, Levine [12] introduced the concept of generalized closed set in the topological spaces. Many mathematicians started generalizing closed sets in recent years. In 1993, N. Palaniappan and K. Chandrasekhara Rao [22] introduced regular generalized closed (rg -closed) sets. M. K. R. S. Veerakumar introduced g^* closed sets [26], $g\#$ closed sets [25] in topological spaces. The aim of this paper is to introduce a new class of sets namely $(r^*g^*)^*$ closed sets in topological spaces and study some basic properties.

2. Preliminaries

Definition:2.1: A subset A of a space X is called

- (1) a preopen set if $A \subseteq \text{int}(\text{cl}(A))$ and a preclosed set if $\text{cl}(\text{int}(A)) \subseteq A$.
- (2) a semi-open set if $A \subseteq \text{cl}(\text{int}(A))$ and a semi-closed set if $\text{int}(\text{cl}(A)) \subseteq A$.
- (3) an α -open set if $A \subseteq \text{int}(\text{cl}(\text{int}(A)))$ and a α -closed set if $\text{cl}(\text{int}(\text{cl}(A))) \subseteq A$.
- (4) A semi-preopen set (β -open) if $A \subseteq \text{cl}(\text{int}(\text{cl}(A)))$ and a semi-preclosed set (β -closed) if $\text{int}(\text{cl}(\text{int}(A))) \subseteq A$.

Definition:2.2: A subset A of a space X is called

1. A Regular closed[24] if $\text{cl}(\text{int}(A))=A$.
2. A generalized closed (g closed) [12] set if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open.
3. A Regular generalized closed (rg -closed) [22] set if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open.
4. An α -generalized closed (αg - closed) [8] set if $\alpha \text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open.
5. A semi generalized closed (briefly sg - closed) [6] if $\text{scl}(A) \subseteq U$ whenever $(A) \subseteq U$ and U is semiopen in X .

6. A generalized semi closed (briefly gs - closed) [2] if $\text{scl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open in X .
7. A weekly generalized closed (briefly wg - closed) [13] if $\text{cl}(\text{int}(A)) \subseteq U$ whenever $A \subseteq U$ and U is open in X .
8. A generalized pre regular closed (gpr closed)[10] if $\text{pcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open.
9. A g^* closed [26] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is g -open.
10. A regular weakly generalized semi closed (rwg closed) [18] if $\text{cl}(\text{int}(A)) \subseteq U$ whenever $A \subseteq U$ and U is regular open.
11. A g^{**} closed [21] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is g^* -open.
12. A $g\#$ closed [25] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is αg open.
13. A generalized semi-preclosed closed (gsp closed)[9] if $\text{spcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open.
14. A generalized semi-preclosed star closed ($(gsp)^*$ closed)[20] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is gsp open.
15. A generalized preclosed closed (gp closed) [14] if $\text{pcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open.
16. A gp^* closed [11] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is gp -open.
17. A regular \wedge generalized closed ($r\wedge g$ closed)[23] if $\text{gcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open.
18. A regular generalized b -closed (rgb closed) [15] if $\text{bcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open.
19. A mildly generalized closed (mildly g closed) [17] if $\text{cl}(\text{int}(A)) \subseteq U$ whenever $A \subseteq U$ and U is g -open.
20. A r^*g^* closed set [16] if $\text{rcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is g -open.

3. Basic Properties of $(r^*g^*)^*$ -Closed Sets

Definition 3.1: A subset A of a topological space (X, τ) is called a $(r^*g^*)^*$ -closed set if $cl(A) \subseteq U$ whenever $A \subseteq U$ and U is r^*g^* -open.

Example 3.2:

Let $X = \{a, b, c\}$, $\tau = \{\emptyset, X, \{a\}, \{b\}, \{a, b\}\}$
 Closed sets = $\{\emptyset, X, \{b, c\}, \{a, c\}, \{c\}\}$
 r^*g^* open sets of X are $\emptyset, X, \{a\}, \{b\}, \{a, b\}$
 $(r^*g^*)^*$ closed set are $\{\emptyset, X, \{c\}, \{b, c\}, \{a, c\}\}$

Proposition 3.3

Every closed set is $(r^*g^*)^*$ -closed.

Proof:

Let A be any closed set in X

To prove : A is $(r^*g^*)^*$ - closed set

Let $A \subseteq U$ and U be any r^*g^* -open set in X

A is closed $\Rightarrow cl(A) = A \subseteq U$

$\Rightarrow cl(A) \subseteq U$

$\Rightarrow A$ is $(r^*g^*)^*$ -closed set in X .

Hence every closed set is $(r^*g^*)^*$ -closed.

The converse is not true as seen from the following example.

Example 3.4 Let $X = \{a, b, c\}$, $\tau = \{\emptyset, X, \{a\}, \{a, c\}\}$.

Here $\{a, b\}$ is $(r^*g^*)^*$ closed but not closed.

Proposition 3.5

Every g^* closed set is $(r^*g^*)^*$ closed set.

Proof: Let $A \subseteq U$ Where U is r^*g^* open. Since every r^*g^* open set is g^* open set we have $cl(A) \subseteq U$. Therefore $cl(A) \subseteq U$ where U is r^*g^* open. Hence A is $(r^*g^*)^*$ closed.

The converse is not true as seen from the following example.

Example 3.6 Let $X = \{a, b, c\}$, $\tau = \{\emptyset, X, \{a\}, \{b, c\}\}$.

Here $\{b\}$ is $(r^*g^*)^*$ closed but not a g^* closed.

Proposition 3.7

Every $(r^*g^*)^*$ -closed set is rg -closed

Proof:

Let A be any $(r^*g^*)^*$ -closed set in X

To prove : A is rg -closed set

Let $A \subseteq U$ and U be a regular-open set in X .

Since every regular open set is r^*g^* open we have $cl(A) \subseteq U$

$\Rightarrow cl(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open

in X

$\Rightarrow A$ is rg -closed set in X

Hence every $(r^*g^*)^*$ closed set is rg -closed.

Example 3.8

The converse need not be true as seen from the following example

Let $X = \{a, b, c\}$ and $\tau = \{X, \emptyset, \{a, b\}, \{a\}, \{b\}\}$

Here $\{a, b\}$ is rg closed but not $(r^*g^*)^*$ closed.

Proposition 3.9

Every $(r^*g^*)^*$ -closed set is gpr closed.

Proof:

Let $A \subseteq U$ and U be an regular open set in X . Since every regular open set is r^*g^* open we have $cl(A) \subseteq U$

But $pcl(A) \subseteq cl(A) \subseteq U$

$\Rightarrow pcl(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open

in X which implies A is gpr closed.

Hence every $(r^*g^*)^*$ closed set is gpr -closed.

Example 3.10

The converse need not be true as seen from the following example.

Let $X = \{a, b, c\}$ and $\tau = \{X, \emptyset, \{a, b\}\}$

Here $\{a\}$ is gpr closed but not $(r^*g^*)^*$ closed.

Proposition 3.11:

Every $(r^*g^*)^*$ -closed set is rwg -closed.

Proof:

Let $A \subseteq U$ and U be an regular open . Since every regular open set is r^*g^* open we have $cl(A) \subseteq U$

But $cl(int(A)) \subseteq cl(A) \subseteq U$

$\Rightarrow cl(int(A)) \subseteq U$ whenever $A \subseteq U$ and U is regular

open in X

Hence A is rwg -closed set in X .

Hence every $(r^*g^*)^*$ closed set is rwg -closed.

Example:3.12

The converse need not be true as seen from the following example.

Let $X = \{a, b, c\}$, $\tau = \{X, \emptyset, \{a\}\}$

Here $\{a, b\}$ is $(r^*g^*)^*$ closed but not rwg closed

Proposition 3.13:

Every g^{**} closed set is $(r^*g^*)^*$ -closed set.

Proof: Let $A \subseteq U$ and U be an r^*g^* open set in X . Since every r^*g^* open set is g^* open we have $cl(A) \subseteq U$. Therefore $cl(A) \subseteq U$ where U is r^*g^* open. Hence A is $(r^*g^*)^*$ closed.

Example:3.14

The converse need not be true as seen from the following example.

Let $X = \{a, b, c\}$, $\tau = \{X, \emptyset, \{a\}, \{a, c\}\}$

Here $\{a\}$ is $(r^*g^*)^*$ closed but not g^{**} closed.

Proposition 3.15:

Every $g^\#$ closed set is $(r^*g^*)^*$ -closed set.

Proof:

Let $A \subseteq U$ and U be an r^*g^* open set in X . Since every r^*g^* open set is $g^\#$ open we have $cl(A) \subseteq U$. Hence $cl(A) \subseteq U$ where U is r^*g^* open.

Hence every $g^\#$ closed set is $(r^*g^*)^*$ closed.

Example:3.16

The converse need not be true as seen from the following example

Let $X=\{a,b,c\}, \tau =\{X, \phi, \{a\},\{b,c\}\}$
 Here $\{b\}$ is $(r^*g^*)^*$ closed but not $g\#$ closed.

Proposition 3.17:

Every $(gsp)^*$ closed set is $(r^*g^*)^*$ -closed.

Proof:

Proof follows from the definition of $(gsp)^*$ closed set and fact that r^*g^* open implies gsp open.

Example:3.18

The converse need not be true as seen from the following example

Let $X=\{a,b,c\}, \tau =\{X, \phi, \{b\},\{a,c\}\}$

Here $\{a,c\}$ is not $(gsp)^*$ closed but $(r^*g^*)^*$ closed

Proposition 3.19: Every gp^* closed set is $(r^*g^*)^*$ -closed.

Proof: Proof follows from the definition of $(gp)^*$ closed set and fact that r^*g^* open implies gp open

Example:3.20

The converse need not be true as seen from the following example

$X=\{a,b,c\}, \tau =\{X, \phi, \{c\},\{a,c\}\}$

Here $\{a,c\}$ is not $(gp)^*$ closed but $(r^*g^*)^*$ closed .

Proposition 3.21: Every $(r^*g^*)^*$ closed set is $r^{\wedge}g$ -closed.

Proof:

Let $A \subseteq U$ and U be an regular open set in X . Since every regular open set is r^*g^* open we have $cl(A) \subseteq U$
 But $gcl(A) \subseteq cl(A) \subseteq U$

$\Rightarrow gcl(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open in X

Which implies A is $r^{\wedge}g$ closed.

Hence every $(r^*g^*)^*$ closed set is $r^{\wedge}g$ -closed

Example:3.22

The converse need not be true as seen from the following example

$X=\{a,b,c\}, \tau =\{X, \phi, \{a\},\{b\},\{a,c\}\}$

Here $\{a,b\}$ is $(r^{\wedge}g)$ closed but not $(r^*g^*)^*$ closed .

Proposition 3.23: Every $(r^*g^*)^*$ closed set is rgb -closed.

Proof:

Let $A \subseteq U$ and U be an regular open set in X . Since every regular open set is r^*g^* open we have $cl(A) \subseteq U$

But $bcl(A) \subseteq cl(A) \subseteq U$

$\Rightarrow bcl(A) \subseteq U$ whenever $A \subseteq U$ and U is regular open in X Which implies A is rgb closed.

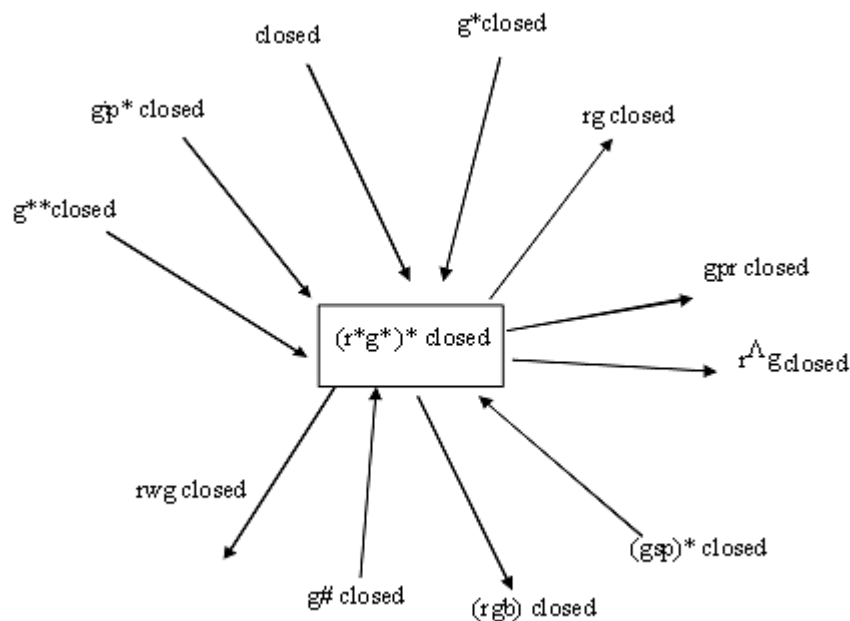
Example:3.24

The converse need not be true as seen from the following example

Let $X=\{a,b,c\}, \tau =\{X, \phi, \{c\}\}$

Here $\{b\}$ is rgb closed but not $(r^*g^*)^*$ closed.

Thus We have the following diagram.



Here $A \rightarrow B$ represents A implies B . But not conversely

Remark:3.25

$(r^*g^*)^*$ closed sets and semi closed sets are independent of each other as seen from the following examples.

Example:3.26

Let $X=\{a,b,c\}, \tau =\{X, \phi, \{a\},\{b\},\{a,b\}\}$.Here $\{b\}$ is semi closed but not $(r^*g^*)^*$ closed

Let $X=\{a,b,c\}, \tau =\{X, \phi, \{a\},\{a,c\}\}$.Here $\{a,b\}$ is $(r^*g^*)^*$ closed but not semi closed

Remark: 3.27

$(r^*g^*)^*$ closed sets and semi pre closed sets are independent of each other as seen from the following examples.

Example :3.28

Let $X=\{a,b,c\}$, $\tau =\{X, \phi, \{a\}, \{b\}, \{a,b\}\}$. Here $\{a\}$ is semi pre closed but not $(r^*g^*)^*$ closed.

Example 3.29: Let $X=\{a,b,c\}$, $\tau =\{X, \phi, \{a\}, \{a,c\}\}$.Here $\{b\}$ is $(r^*g^*)^*$ closed but not semi pre closed.

Remark: 3.30

The following example shows that $(r^*g^*)^*$ closedness is independent from sg closedness , gs closedness , pre closedness and wg closedness

Example 3.31

Let $X=\{a,b,c\}$, $\tau =\{X, \phi, \{a\}, \{a,c\}\}$

- (i) $\{c\}$ is sg closed but not $(r^*g^*)^*$ closed . $\{a\}$ is $(r^*g^*)^*$ closed but not sg closed .
- (ii) $\{c\}$ is gs closed but not $(r^*g^*)^*$ closed. $\{a\}$ is $(r^*g^*)^*$ closed but not gs closed.
- (iii) $\{c\}$ is pre closed but not $(r^*g^*)^*$ closed. $\{a\}$ is $(r^*g^*)^*$ closed but not pre closed .
- (iv) $\{c\}$ is wg closed but not $(r^*g^*)^*$ closed. $\{a\}$ is $(r^*g^*)^*$ closed but not wg closed

Remark:3.32

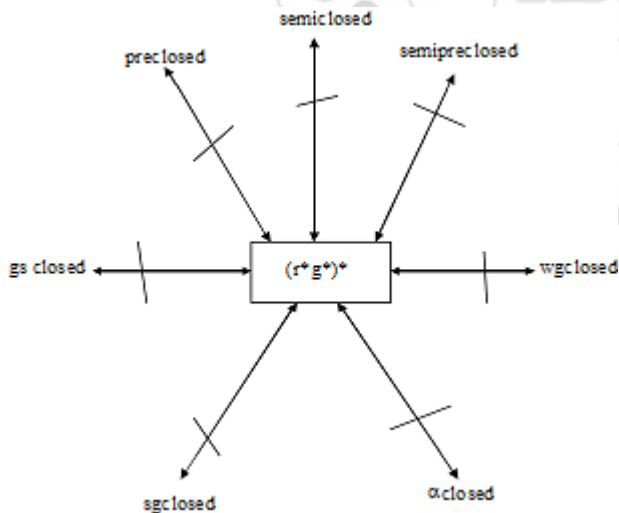
$(r^*g^*)^*$ closed sets and α -closed sets are independent of each other as seen from the following examples.

Example:3.33

Let $X=\{a,b,c\}$, $\tau =\{X, \phi, \{a\}, \{b\}, \{a,b\}\}$. Here $\{c\}$ is $(r^*g^*)^*$ closed but not α -closed .

Let $X=\{a,b,c\}$, $\tau =\{X, \phi, \{b\}, \{a,b\}\}$. Here $\{a\}$ is α -closed but not $(r^*g^*)^*$ closed.

Thus we have the following diagram



A represents A and B are independent of Each other.

Theorem:3.34

The union of two $(r^*g^*)^*$ -closed sets is $(r^*g^*)^*$ -closed set

Proof:

let A and B be $(r^*g^*)^*$ -closed sets in X and U be any r^*g^* -open set containing A and B such that $cl(A) \subseteq U$, whenever $A \subseteq U$ and U is r^*g^* -open and $cl(B) \subseteq U$, whenever $B \subseteq U$ and U is r^*g^* -open .Let $A \cup B \subseteq U$. Then $A \subseteq U$ and $B \subseteq U$.

Hence $cl(A \cup B) = cl(A) \cup cl(B) \subseteq U$

$\Rightarrow cl(A \cup B) \subseteq U$ whenever $A \cup B \subseteq U$ and U is $(r^*g^*)^*$ -open set in X .

Hence $A \cup B$ is $(r^*g^*)^*$ -closed.

Remark: 3.35 The intersection of two $(r^*g^*)^*$ closed sets need not be $(r^*g^*)^*$ -closed.

Let $X=\{a,b,c\}$ $\tau =\{\phi, X, \{a\}\}$. $(r^*g^*)^*$ closed sets are $\{\phi, X, \{b\}, \{c\}, \{a,b\}, \{b,c\}, \{a,c\}\}$. The intersection of $\{a,b\}$ and $\{a,c\}$ is not a $(r^*g^*)^*$ -closed set.

Proposition 3.36:

If A is both $(r^*g^*)^*$ -open and $(r^*g^*)^*$ -closed, then A is closed.

Proof:

Let A be r^*g^* -open set in X and also $(r^*g^*)^*$ -closed set in X $Cl(A) \subseteq U$ whenever $A \subseteq U$ and U is $(r^*g^*)^*$ -open set in X .

Since A is r^*g^* -open. Take $U =A \Rightarrow cl(A) \subseteq U =A \Rightarrow cl(A) \subseteq A$

But $A \subseteq cl(A) \Rightarrow Cl(A) = A$.Hence A is closed.

Proposition:3.37 Let A be a $(r^*g^*)^*$ -closed set of (X, τ) . Then $cl(A)-A$ does not contain any non empty r^*g^* closed set.

Proof: Let F be a r^*g^* closed set such that $F \subseteq cl(A)-A$. Then $A \subseteq X-F$. Since A is $(r^*g^*)^*$ -closed and $X-F$ is r^*g^* -open we have $cl(A) \subseteq X-F$. This implies $F \subseteq X-cl(A)$. So $F \subseteq (X-cl(A)) \cap (cl(A)-A) \subseteq (X-cl(A)) \cap cl(A)$ which implies $F = \phi$. Hence the theorem.

Proposition: 3.38 If A is mildly g closed and open then A is $(r^*g^*)^*$ -closed.

Proof: Let $A \subseteq U$ and U is r^*g^* -open set. But every r^*g^* -open is g-open, We have $cl(int(A)) \subseteq U$ which implies $cl(A) \subseteq U$ where U is r^*g^* -open. Hence A is $(r^*g^*)^*$ -closed.

Proposition 3.39:

If A is $(r^*g^*)^*$ - closed set of (X, τ) , such that $A \subseteq B \subseteq cl(A)$, then B is also a $(r^*g^*)^*$ -closed set of (X, τ) .

Proof:

Given that A is $(r^*g^*)^*$ - closed set of (X, τ) .

$\Rightarrow cl(A) \subseteq A$ whenever $A \subseteq U$ and U is r^*g^* -open set in X

To prove : B is $(r^*g^*)^*$ -closed set .

Let $B \subseteq U$. Now $cl(B) \subseteq cl(A) \subseteq U$

$\Rightarrow cl(B) \subseteq U$ whenever $B \subseteq U$ and U is $(r^*g^*)^*$ open..
 $\Rightarrow B$ is $(r^*g^*)^*$ -closed

4. $(r^*g^*)^*$ Open Sets

Definition: 4.1 A set $A \subseteq X$ is called $(r^*g^*)^*$ open set if its complement is $(r^*g^*)^*$ closed.

Theorem: 4.2 A subset $A \subseteq X$ is $(r^*g^*)^*$ open iff there exists a r^*g^* closed set F such that $F \subseteq int A$ whenever $F \subseteq A$

Proof : Let A be a $(r^*g^*)^*$ closed and $F \subseteq A$ then $X-A \subseteq X-F$ where $X-F$ is $(r^*g^*)^*$ open .Therefore $Cl(X-A) \subseteq X-F$ which implies $X - (int A) \subseteq X-F$ Therefore we have $F \subseteq int (A)$
 Conversely suppose $F \subseteq int A$ where F is $(r^*g^*)^*$ closed $F \subseteq A$

Let $X-A \subseteq U$ where U is $(r^*g^*)^*$ open
 Then $X-U \subseteq A$ where $X-U$ is $(r^*g^*)^*$ closed by hypothesis $X-U \subseteq int A$ which implies $X- int (A) \subseteq U$ Which implies $Cl (X-A) \subseteq U$ where U is $(r^*g^*)^*$ open and hence $X -A$ is $(r^*g^*)^*$ closed.
 Hence A is $(r^*g^*)^*$ open.

Theorem 4.3: If $int A \subseteq B \subseteq A$ and if A is $(r^*g^*)^*$ open then B is $(r^*g^*)^*$ open

Proof : $B \subseteq A$ implies $X-A \subseteq X-B$
 $int A \subseteq B$ implies $X-B \subseteq X- int A$
 That is $X-A \subseteq X-B \subseteq X - int (A) = Cl (X-A)$
 Since $X-A$ is $(r^*g^*)^*$ closed, by theorem (3.39) $X -B$ is $(r^*g^*)^*$ closed which implies B is $(r^*g^*)^*$ open.

Theorem4.5 : Let $B \subseteq X$. if B is $(r^*g^*)^*$ open and $int B \subseteq A$ then $A \cap B$ is $(r^*g^*)^*$ open.

Proof : It is given that $int B \subseteq A$ and also $int B \subseteq B$, implies $int B \subseteq A \cap B \subseteq B$. By theorem 3.39 $A \cap B$ is $(r^*g^*)^*$ open.

Theorem 4.6: A set A is $(r^*g^*)^*$ closed if $cl(A) - A$ is $(r^*g^*)^*$ open

Proof: Let A be $(r^*g^*)^*$ closed
 Let F be a r^*g^* closed set such that $F \subseteq cl (A)-A$
 Then by theorem (3.37) $F = \varnothing$
 $F \subseteq int (cl (A)-A)$
 $\Rightarrow cl (A) -A$ is $(r^*g^*)^*$ open by Theorem (4.2) .

5. Conclusion

In this paper we have introduced $(r^*g^*)^*$ closed sets and $(r^*g^*)^*$ open sets and studied some properties.This class of sets can be used to discuss the notion of Continuity, Compactness and connectedness and also can be extended to other topological spaces like Fuzzy & Bitopological Spaces.

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