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Patron-in-Chief's Message

I am delighted to have the opportunity to share a few thoughts at the time of publication of the upcoming issue of BJEAS. In this era of technological advancements, it is necessary that research work carried out in various engineering and sciences disciplines is recognized and propagated properly. BJEAS is a step towards disseminating high-quality research nationally as well as globally while maintaining the unique recognition of Balochistan. I believe that this Journal will become a hallmark of research in the future. As Patron-in-Chief, I will ensure that BJEAS remains in line with rapidly shifting scientific communication landscape, while also maintaining and intensifying the high standards of academic excellence.

I sincerely hope that research articles published by BJEAS will provide insightful and stimulating information to readers and scholars that will shape our future and lead the way to extraordinary discoveries.

Prof. Dr. Ehsanullah Khan Kakar
Vice Chancellor
Balochistan UET, Khuzdar

Aims of Journal

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Assessment of Water use Efficiency Using Different Irrigation Methods at Uthal Balochistan

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***Abstract*—The study was conducted at the field station Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS) Uthal. Before the experimental setup, the soil analysis was done. The Maize verity (Akbar) at the rate of 33.8 grams was used in flood, furrow, drip, and control irrigation at an equal ratio. The total discharge was recorded for 70 days, 2,250, 1890, 1710, and 30 liters for flood, furrow, drip, and control irrigation. Infiltration and field capacity was observed at 39.45 % and 60.55 % percent it shows that infiltration and field capacity was quite in range the average infiltration rate was observed at 10.11 minutes. Calculating the yield of maize crop, it has been investigated that drip irrigation is the best method rather than flood and furrow irrigation less amount of 1710 liters discharge was applied during the base period of the maize crop to get the maximum yield of 20.15 Kg by drip irrigation. It was revealed that drip irrigation is a more efficient method of irrigation, during the study maximum number of plants 55.40, the number of leaves 9.01, and the length of plant leaves 46.94, leaf area index was 424 cm^2 was examined under the drip irrigation by the limited supply of water/discharge. Overall, it has been examined through the results that drip irrigation is the best method farmers are suggested to apply trip irrigation for maize crop cultivation instead of flood and furrow to get a maximum yield of crop per drop of water and to boost the water conservation practices.**

***Keywords*—Groundwater Level, Spatial Interpolation Methods, IDW**

1. INTRODUCTION

According to the Economic Survey of Pakistan, the total population of Pakistan is 222 million with an average increasing population rate of 1.94% annually. The agriculture is not only the source of food for the countrymen but the source of income as well. The irrigation plays an important role for agriculture in arid and semi-arid areas. Hence the available water resources of Pakistan are scare since last three decades. The present situation is an emerging threat for all uses of water by 2050. The ground water exploitation may cause increasing the salinity may reduce the crop yield. Water is a basic element for growing crops and their survival [67]. The prior study observed that various approaches are most effective for achieving sustainable water management practices [21]. Water use efficiency plays an important role in irrigation for rising crops to produce more crops per drop of water [1].

Irrigation controls the arid conditions for the cultivation of crops [42]. According to American Water Works Association, 1985 both volume of water and the time describe to pass the water through the soil strata. The water passes through the soil in the shape of infiltration, deep percolation, evaporation, transpiration while the consumptive use gives a measurement of flow rate. The water use efficiency may be defined as the ratio of grain yield to total actual evapotranspiration drastically raise yield to ensure food security [24]. The water use efficiency recognized for all crops and crucial need to combat food security for coming generations in the world [60]. Water use efficiency is used to evaluate the crop water productivity performance on various irrigation regimes. It is also very important to evaluate the consumptive use of the crop [19]. Maize is one of the fodder and cereal crops grown in various environments and climates [31]. The water use efficiency is crucial to optimize irrigation regimes for maize crop in warm climate [41].

The soil fertility and crop productivity by irrigation is a novel approach for enhancing maize yield by water use efficiency [22]. Though the yield of maize crop can be decreased due to seasonal variations and climate change patterns. It is important to estimate crop production and to manage risk factors by adjusting key management practices [55]. During 2016-17, a major area of 1334 thousand hectares has been sown under maize crop, the survey showed that the significant increase of 12% by last year. The maize yield was recorded 6.130 million tons during the fiscal year against the previous yield of 5.271 million tons with increase of 16.3 % during the previous year. The record production has been achieved by using best irrigation practices. This is too possible to grow and harvest maize crops under controlled conditions using best method of irrigation and by intensive fertilizer uptake for better yield. That's why the study has been conducted to compare the water use efficiency of maize crop using different irrigation methods.

2. MATERIALS AND METHODS

2.1 Experimental Design

The experiment was conducted at the experimental field Lasbela University of Agriculture, Water and Marine Sciences, Uthal district Lasbela, Balochistan. in Randomized Complete Block Design (RCBD) with a 1 mx1 m block size. Three treatments Flood Irrigation (FL), Furrow Irrigation (FR), and Drip Irrigation (DR) along with control were used with three replications. For drip irrigation, the emitter discharge was set at 1L/emitter. While for furrow and flood irrigation, crops were irrigated 8 times throughout the season. The land was prepared, and a soaking dose was given to the field; after field capacity tillage was carried out; the seed was broadcasted; The maize variety "Akbar" was grown. The maize row arrangement was 60 cm with plants spread out 40 cm apart. Maize was fixed at 52,000 plants per acre. Di-Ammonium Phosphate 'DAP' 183.6 grams was provided for increasing fertility and growth of the crop during wet tillage. While early first irrigation Urea 'N-46' was given to all plots at the rate of 2000 grams.

2.2 Soil Analysis

Soil samples from four corners and center at depth of 0.6 feet were taken and mixed brought to the laboratory; after mixing sample was weighed on the electrical balance. Soil texture was known with the help of a sieve shaker. The size of the sieves was 5 mm, 2mm, 1.70mm, 1.40mm, 1.18mm, 1, 560-micron, and 250-micron, final size was less than 0.2 microns.

2.3 Measurement of Percolation Rate

The percolation rate was determined through the test hole method the hole was drilled with an augur at the depth of 6.0 (six) inches having a diameter of 3.0 (three) inches 1.0-liter water was taken in a beaker water was poured into hole and percolation was measured the analysis of percolation is highlighted in result.

2.4 Measuring the soil moisture content and Field capacity

From homogeneous soil the samples of soil were taken, mixed with each other, and weighted for measuring the moisture content by oven dry (gravimetric method) using the general formula as given below;

(MC=W1-W2/W2*100)
where,
MC= Moisture Content, W1= Weight of wet soil, W2= Weight of dry soil

2.5 Measurement of Evaporation Rate

The evaporation data were acquired from the Agro-meteorological field station Lasbela University of Agriculture, Water and Marine Sciences. The evaporation rate was calculated by the Class-A pan method.

E0= Kp*Epan
Where:
E0=Evaporation rate, Kp=Pan evaporimeter Coefficient, Epan=Eaporation value from Evaporimeter

2.6 Irrigation and Discharge measurement

Before first irrigation the discharge of the source inlet 'pipe' was measured on volumetric basis it was observed that the discharge of the pipe was 1.0 l/sec. After that first irrigation was provided to the field over all 10 irrigations were provided and the discharge was measured for each replication viz: for flood, furrow, and drip and control irrigation the analysis of irrigation discharge is discussed in result.

2.7 Infiltration rate

For calculating infiltration rate soil sample was taken in container, later the sample was measured on electrical weight balance the weight of sample was calculated 50 grams 50 ml water was poured in funnel single tissue paper was used for observing infiltration rate. The infiltration rate was measured in graduated cylinders nine cylinders were used to measure the infiltration rate.

2.8 Observational agronomic parameters

After germination the number of plants, and number leaves were counted in each plot. Further, nine plants from each plot were randomly selected and plant height, plant diameter, leaf height, leaf width, and leaf area index were calculated. Maize was harvested at maturity for yield calculation. The obtained data were statistically analyzed by ANOVA with Least significant difference (LSD) at ($p<0.05$) using SPSS 20 software package.

3. RESULTS AND DISCUSSION

3.1 Soil Texture Analysis

Soil texture play an important role for uptake of the crop production and water use efficiency; crop productivity has been changed due to soil type deep clay and peat soils shows highest water use efficiency and required low amount of irrigation water, sandy soils require high irrigation amount rather than the other type of soil, ineffective use of water resulting in a low yield of the crop. The

current study in table 1 revealed that the ratio of silt was 52%.

3.2 Measurement of Percolation Rate

Percolation rate is the downward movement of water from the soil surface; it removes the rain or irrigation water from the soil surface in the shape of runoff [48]. Agriculture sector is a prime share holder to raise crop, different types of soils have the different percolation rate and various crops have the different consumptive use. Measurement of percolation in irrigation regimes is an important component for water allocation as well as for making the strategies for proper water utilization and water use efficiency. It has been observed during the study that at the initial stage of crop growth/vegetation period there is a high percolation rate. The current study corresponds to knowing the downward movement of the water for better management of the water for crops during irrigation through- ought the base period; hence, it has been calculated by the current study that 1.6ml/s of water was percolated in table 1.

3.3 Measuring the soil moisture content and field capacity

Water present in the pore spaces of the soil is called soil moisture it is generally held in the soil 50 to 200 cm in the upper layer. Soil moisture study is used for biological process of the plant during the irrigation scheduling. It is used to evaluate the weather patterns change, soil evaluation and hydrological modelling etc. A study was conducted for the determination of water content analysis of soil by oven dry/ gravimetric method the main objective of the study was to evaluate the accuracy of the oven-drying method; The temperature of 105°C is a prerequisite for accurate measurement of water in soil which has been used by crops during field capacity for any contact time 12-24 hours for measuring the soil moisture. A microwave oven has been found to be satisfactory for determining soil moisture content gravimetrically of the soil samples to determine the soil moisture by a standard soil drying method [17][68]. The current study is an agreement with the soil moisture content measurement, during the study MC 68.57% and the field capacity 31.43% was observed. The results are mentioned in table 1.

3.4 Measurement of the Evaporation Rate

Irrigation is a comprehensive task to measure the water requirements of the crop and water losses from the field. These water losses have been included evaporation, infiltration, and deep percolation to measure quantities of water needed for irrigation and to calculate the evaporation rate on the physically and practically basis. Evaporation rate from land surfaces can be measured by E0=Kp* Epan. Evaporation from soil by using the crop coefficient in the regional climate and weather patterns [61]. A study was conducted to know the evaporation rate and water requirements of truff grass field in a similar environment and specie. This is possible that water requirements of crops can be calculated by measuring the actual evaporation in climate change and land use patterns. To examine the effect of evaporation the water requirements of grass is an essential task to cope with the climate change patterns especially in arid regions. Furthermore, the other study was conducted on cross components in some maize genotypes under different irrigation practices in randomized complete block design with three replications the evaporation rate was observed by class-Pan. During the study it was observed that in water stress condition the gene of maize was reduced remarkably. Additionally, study was conducted on maize crop through different water regimes to observe the evaporation rate and coefficient of uniformity. Further it was observed that by applying less water may resulted less evaporation rate, it was suggested that by increasing the water quantity the yield of crop can be improved accordingly [26][49].

3.5 Infiltration rate

Infiltration is done downward entry of water into the soil by capillary action trough the force of gravity. Different soils have different water holding /field capacities due to distinct soil texture. It is a process by which water enters the soil through a velocity in a unit time, and the ability of soil to absorb the water. It has been observed that in soil saturation condition the rate of infiltration is decreased. Thus, this will help to hold the water in pores for plant up take [48]. Soil infiltration is a physical property it determines flow rate, deep percolation, and infiltration rate. Soils have the different infiltration rate regarding the soil type and their physical properties viz porosity, bulk density, and particle density. The porosity of clay soil is less than the of silt, sandy and sandy loam soils. Silt and clay soils have less porosity against the sandy soil. Clay and silt soils have less infiltration rate against the sandy/sandy loam. Measurement of infiltration rate is important factor for water use efficiency and water management for the plant growth and metabolism activities. Improving the growth and yield of crops can be done by controlled irrigation [13]. The current study is an agreement with the above study, during the current

study 20.11 ml average water was applied and 40.22% infiltration rate was observed during the average time 10.11 minutes. The results are mentioned in Table 1.

Table 1: Soil properties of the experimental site

Parameters	Observations	
Soil Texture	Gravel	5%
	Sand	18%
	Fine Clay	11%
	Very fine Clay	3%
	Silt	52%
	Clay	11%
Moisture Contents	68.57%	
Field Capacity	31.43%	
Percolation rate	1.6 ml/s	
Evaporation rate	56 mm	
Infiltration rate	40.22%	

3.6 Irrigation and discharge measurement

Irrigation plays a vital role for raising the crop growth. It has been revealed that water is basic element for raising the crop in arid and semi-arid regions. Hence the traditional methods of irrigation are used to improve the plant growth. However, over irrigation may cause of water logging in irrigated areas and affect the plant's growth. Flood, furrow, and basin irrigation were exercised in Umarkot district, Sindh province by a team of researcher to know the irrigation efficiency and consumptive use of crop where results have showed 30 percent less irrigation efficiency in flood irrigation. Though the study it has been suggested that the modern methods sprinkler and drip irrigation system are the best water saving methods for increasing the plan's growth and yield. It was further investigated that drip irrigation has a high tolerance against the speed. Drip is best water saving method with balanced moisture content. During the study high yield and irrigation efficiency was observed in drip irrigations with 70-80 percent water saving [72]. It is suggested in current study that drip irrigation is a best method of irrigation against the flood and furrow irrigation and measurement of discharge have a great importance to cope with the demands of crop and water saving practices. During the current study discharge was observed in each replication. It was recorded in flood irrigation as 2250 litres; in furrow irrigation 1890 liters, and in drip irrigation, 1710 litres were calculated; against the time 500; 420; 380 seconds, respectively. For control irrigation 30, litres discharge was calculated against the time; 60 seconds.

3.7 Effect of the different irrigation methods on the number of maize plants.

During the current study number of maize plants were counted after three weeks (twenty-one days) of the germination in all treatments (flood, furrow, drip, and control). A significant difference in number of maize plants was observed among the different irrigation methods as shown in the table 2. based on the mean performance results, maximum number of plants 55.40 was noted under the drip irrigation method followed by furrow irrigating 53.67 number of plants, however; minimum of number of plants 40.23 were recorded in control treatment. However, the current study is matched significantly with who had conducted two long term experiments by cultivars of Slovenia in specific regions of climate to investigate the effect of plant populations thereby trials were carried-out [10]. During the trial it was examined that plant population was increased then the conventional customs of maize cultivation. Plant population for maize cultivar is one of the important factors for planning maize crop cultivation. The water is playing a major role in increasing the number of leaves it also increases the water productivity of maize crop; it is necessary to cope with the challenges of climate and environmental conditions for better development/growth of maize crop [30]. Irrigation and water management practices increase the plant population and interacted significantly with each other, lack of water increases the stress in plant population, change of cropping and irrigation pattern improve the plant population by spacing and row [37]. It has been reported by, that during the study on maize crop different irrigation practices were examined under limited supply of water by this the highest plant population, plant height was achieved. It has been observed that by limited supply of water the agronomic traits can be developed, and water can be saved accordingly. The current study also revealed that drip irrigation is more efficient and fit method for increasing the number of plants by limited supply of water [50].

Table 2: Effects of various irrigation methods on maize crop

Parameters	Treatments			
	Drip irrigation	Furrow irrigation	Flood irrigation	Control
Total Discharge 70 days	2250	1890	1710	30
No. of Plants	54.74 a	53.94 b	54.91 a	50.12 c
Plant diameter (mm)	26.96 b	27.98 a	27.18 a	25.23 c
No. of leaves /plants	9.02 a	8.56 c	8.81 b	8.01 d
Leaves length (cm)	46.95 a	42.83 b	41.22 bc	34.02 c
Leaves width (cm)	10.17 b	12.12 a	11.06 bc	8.34 c
Leaf area index (cm^2)	424.79 a	384.12 b	389.36 b	350.04 c
Yield (kg)	20.13 a	16.51 b	10.86 c	7.01 d

Means with same letter within row are not significantly different from each other at P>0.005

3.8 Effect of the different irrigation methods on the plant height of maize crop

Plant height was measured from the surface of soil to the top of tassels in centimetres with help of measuring tape. The plant height was measured at 15 days interval from 15-70 days the plant height increased continuously till the growth in all treatments table 2. A significant difference in plant height of the maize crop was observed among the different irrigation methods as shown in the table 2. Based on the mean performance results, maximum plant height 54.92 cm was noted under the flood irrigation method followed the drip irrigation method 54.75 cm. However, a minimum plant height 50.12 cm was recorded in control treatment. In this study plant height was significantly affected by the irrigation methods. The current results agree with other studies investigated that crop height is a basic parameter used to examine the overall crop growth, to forecast crop yield, and to estimate crop biomass in precision agriculture [27][32][62]. stated that individual maize segmentation is the prerequisite for precision the maize crop field this is a challenging task that the maize stalk is usually occluded by leaves between adjacent plants, especially when they grow up. Assessing the plant height is beneficial for evaluating the plant growth, viz crop quality, plant leaves, biomass and predicting the yield of the crop [27][62]. During previous study different treatments were compared using the least significant difference test maize plants were chosen to determine the plant height and water use efficiency. Irrigation method affects the germination and plant growth parameters of maize crop it also affects crop yield and water use efficiency investigated and has been suggested that during the experiment measuring of plant height is important factor to choose suitable irrigation method [16][32]. However, in agronomic traits measuring the plant height has great importance to excess the plant growth by observing the plant height while it depends on best irrigation practice against the drought condition reported by [16]. While during in present study it has been examined that flood irrigation method is best among the other methods of irrigation for increasing the plant height; current study will help to excess the plant height for better attainment of the crop growth.

3.9 Effects of the different irrigation methods on the plant diameter of maize crop

Plant diameter was measured from steam in millimetre with help of vernier calliper. The plant diameter was measured at 15 days interval from 15-70 days the plant diameter increased continuously till the growth in all treatments. A non-significant difference in plant diameter of the maize crop was observed among the different irrigation methods as shown in the table 2. Based on the mean performance results, maximum plant diameter 27.98 mm was noted under the furrow irrigation method followed by the flood irrigation method 27.18 mm. However, a minimum plant diameter 26.93 mm was recorded in control treatment. It has been observed that by using different irrigation method the plant diameter and growth of the maize crop can be increased, the dynamic change observed in both water use efficiency and growth of maize crop while in Nebraska during the experiment; it was observed that furrow irrigation have increased the dynamic change in water use efficiency and growth of maize crop by increasing the stem/plant diameter and leaf area index respectively as reported by the [33]. Measuring the stem diameter growth of the crops has a prominent co-relationship with water. Whereas stem diameter is an important agronomic trait which is used to evaluate the stalk strength and biomass, also characterization status of water, water potential, shrinkage, evaporation, transpiration water balance, irrigation, and irrigation scheduling etc. Measuring the stem diameter is an important factor for water-saving practice in irrigation [11][15][46]. The current study revealed non significance difference in stem diameter in treatments hence maximum plant diameter was noted under the furrow irrigation method followed by the flood irrigation method however, a minimum result of plant diameter was recorded in control treatment.

3.10 Effects of the different irrigation methods on the number of plant leaves of maize crop

Plant leaves were counted at the interval of 15 days from 15-70 days. The numbers of plants were increased continuously till 70 days in all treatments including control in table 2. A significant difference in number of plant leaves of the maize crop was observed among the different irrigation methods. Based on the mean performance results, maximum number of plant leaves 9.01 was noted under the drip irrigation method followed the flood irrigation method 8.81. However, minimum results of number of plant leaves 8.0 were recorded in control treatment. During the study it was recorded that good practices of irrigation water may cause increase leaves number. It was also observed that soil water dynamics may change in water portion in leaf and will increase the plant leaf area against the conventional irrigation practices in maize crop

which effect the crop production and yield [76]. The maize accounts for one-fourth of annual global cereal crop mostly grown in many parts of the world, vegetative growth of maize may result in increases number of leaf area and stem of the crop by best irrigation practices [25]. Effective irrigation management strategy may help to improve plant growth for better response of the maize crop in all traits, in the current study it has been mentioned that a significant difference in number of plant leaves of the maize crop among the different irrigation methods maximum number of plant leaves were noted under the drip irrigation method followed the flood irrigation method however, minimum results of number of plant leaves were recorded in control treatment.

3.11 Effect of the different irrigation methods on the length of plant leaves of maize crop

Length of plant leaves was measured in centimetre with help of measuring tape. The length of plant leaves was measured at 15 days interval during the plant growth the length of plant leaves increased continuously till the growth period of the crop in all treatments including control in table 2. A non-significant difference in length of plant leaves of the maize crop was observed among the different irrigation methods as shown in the table 2 based on the mean performance results, maximum length of plant leaves 46.94 cm was noted under the drip irrigation method followed the furrow irrigation method 42.94 cm. However, minimum length of plant leaves 34 cm was recorded in control treatment. Study was conducted in Pakistan regarding the maize crop it was observed that drought is a major threat for agriculture; it is lethal stress disturbing the crop growth metabolic activities such as reduction in number of leaves, leaf area leaf width and height. It will also affect the cobs and grain size and yield of the crop according to [12]. Maize is widely grown in China for food grain Leaf area is an increasing trend in the slicking stage of maize plant it was observed that due to exchange of elevated concentration of carbon-dioxide leaf area Length and Width of plant can be increased. During the experiment it was observed that by the exchange of carbon dioxide and irrigation application a great effect was observed in increasing the leaf area of maize plant according to [54]. In the current study it has mentioned that non significance difference was observed in length of plant leaves in treatments hence maximum length of plant leaves was noted under the drip irrigation method followed by the furrow irrigation method however, a minimum result length of plant leaves was recorded in control treatment.

3.12 Effect of the different irrigation methods on the plant leaves width of maize crop

Leaves width of maize crop was measured from the centre of the plant in centimetre with help of measuring tape. The width of plant leaves was measured at 15 days interval from 15-70 days the width of plant leaves increased continuously till 70 days in all treatments including control in table 2. A significant difference in plant leaves width of the maize crop was observed among the different irrigation methods as shown in the table 2. Based on the mean performance results, maximum plant leaves width 12.12 cm was noted under the furrow irrigation method followed the flood irrigation method 11.06 cm. However, minimum plant leaves width 8.34 cm was recorded in control treatment. It has been revealed that during the experiment measuring of plant parameters including the plant width is important factor during the plant growth period of the maize crop, irrigation increase the plant width and other parameters of the maize crop during maturity period in other study during the various irrigation regimes, it has been investigated that an increase was observed in the morphological traits 'leaf area' of the Brassica juncea. L; plant by uptake of the fertilizer. It was also mentioned that water stress may affect the morphological orders of the plant [16][64]. Further it has been stated that water is important factor in agriculture increasing the leaf area as well other growth parameters of the maize crop by best environmental conditions, it is aspire to conduct a detailed study for conserving the water use to increase the leaves width by proper moisture retention while in our study proper irrigation was applied with uptake of the fertilizers moreover in this study significance has been observed in maize crop by allowing the drip irrigation instead of flood irrigation our study is an agreement with the above studies a significant difference in plant leaves width of the maize crop was observed among the different irrigation methods based on the mean performance results, maximum plant leaves width was noted under the furrow irrigation method followed the flood irrigation method however minimum results of plant leaves width was recorded in control treatment [30].

3.13 Effect of the different irrigation methods on the plant leaf area index of maize crop

Leaf area index of the plants was calculated by multiplying the leaf length and leaf width centimetre squares. The plant leaves height and

width were measured at 15 days interval from 15-70 days the plant leaves height and width increased continuously till 70 days in all treatments including control in table 2. A non-significant difference in plant leaf area index of the maize crop was observed among the different irrigation methods as shown in the table 2. Based on the mean performance results, maximum plant leaf area index 424 cm^2 was noted under the drip irrigation method followed the flood irrigation method 389 cm^2. However, minimum leaf area index 350 cm^2 was recorded in control treatment. leaf area index is the physical property which occur in the process of biophysical environment, it seems that when stress occur in drought condition better results can be achieved by proper water use and choice of irrigation methods. It aims to conduct a comprehensive study for conserving the water use; the drip irrigation is best application for providing water to maize crop and to increase in plant growth and physiological traits of leaf index area [63]. Leaf area index (LAI) is the important component of the plant to quantify the crop growth, yield and water requirements of crop in controlled condition, by using the different irrigation practices and water regimes. During the current study it has been revealed that a non-significant difference in plant leaf area index of the maize crop was observed among the different irrigation methods based on the mean performance results, maximum plant leaf area index was noted under the drip irrigation method followed the flood irrigation method however minimum results of plant leaf area index was recorded in control treatment [43].

3.14 Effect of the different irrigation methods on the yield of maize crop

After seventy days the crop was harvested, and yield of the crop was calculated for each treatment flood, furrow, and drip irrigation. A significant difference in the yield of the maize crop was observed among the different irrigation methods as shown in the Table 2. Based on the mean performance results, maximum yield 20.15Kg was noted under the drip irrigation method followed the furrow irrigation method 16.5Kg However, minimum yield of maize crop 7Kg was recorded in control treatment. Drip irrigation is used to increase the water use efficiency due to slow movement of water in the root zone of the crop as well as in the soil capillaries. To increase the yield against the other methods of irrigation, deep irrigation in excess reduces the plant growth and yield of the crop, the efficient use of water is used to control the water losses. Further it has been revealed that water can be saved by improved water management practices this can be done by drip irrigation according to Water availability and freshwater resources is a major problem in Pakistan and other countries of the world. It is very necessary to manage the water resources with the existing water resources availability to cope with water scarcity as well as to meet the water demands of crop in future. An experiment was conducted a team of researchers at Sindh Agriculture University Tando jam, Pakistan to compare drip and furrow irrigation methods to check out the bulk density, infiltration rate, field capacity, pH, and soil texture also the plant height, head diameter, stem girth, number of seeds per head, weight of the seeds per head, seed index and seed yield was measured in drip and furrow irrigation method [63]. It was recorded that the emission uniformity of drip irrigation system ranged between 87.8 to 90.8% it was revealed that the results of drip irrigation method was satisfactory and was higher than the furrow irrigation in yield and water use efficiency. It was examined that drip irrigation method is better in all respects it should be practiced in water scare regions where water availability is less [69]. The current study matched with the said study regarding high yield of maize crop. It was examined by the current study that a significant difference in the yield of the maize crop was observed among the different irrigation methods the yield of irrigation based on the mean performance results, maximum yield was noted under the drip irrigation method followed the furrow irrigation method however minimum results yield of maize crop was recorded in control treatment.

4. CONCLUSION

During the study maximum number of plants were noted in drip irrigation also the maximum number of leaves were recorded in drip by limited supply of water. In current study it has mentioned maximum length of plant leaves was noted under the drip irrigation maximum plant leaf area index 424 cm^2 was also observed under the drip irrigation method maximum yield 20.15Kg was calculated under the drip irrigation. Overall, it has been examined through the result that drip irrigation is best method than the flood and furrow irrigation methods. Farmers are suggested to apply the drip irrigation for maize and other crop cultivation instead of flood and furrow to get a maximum yield of crop on per drop of water and to boost the water conservation practices in agriculture sector.

5. DECLARATION OF INTEREST STATEMENT

The authors have no conflict of interest in manuscript writing and data publication.

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Modeling Spatiotemporal Changes in Groundwater Levels: Case Study of Lahore, Pakistan

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***Abstract*—For planning and sustainable use of an aquifer, monitoring groundwater is important. Understanding the aquifer response to water level information is very important. In this study, the data on groundwater levels for the summer and winter seasons from 14 observation wells were collected. This data was for the period of 2003 and 2018 and used to model the groundwater level changes spatially and temporally in the Lahore division. Inverse Distance Weighing, Radial Basis Function, and ordinary Kriging Interpolation techniques were used to model these changes. The accuracy of these different interpolation methodologies was assessed by Coefficient of determination (R2), validation, Root-mean-square error (RMSE), and Mean Absolute Error (MAE). Results show that the radial basis function techniques give more satisfactory results than the other two techniques. While on the other hand, the Inverse Distance Weighing (IDW) techniques show the least promising results. It has also been observed from results that the decline in groundwater levels is because of excessive pumping from drilled wells in the city center. This decline in groundwater levels was also seen in the study area where irrigation pumping wells were installed.**

***Keywords*—Groundwater, Spatial Interpolation, IDW, RBF, OK**

1. INTRODUCTION

Groundwater is an important source of water for irrigation and domestic purposes. In the past few years, the abstraction of groundwater has increased due to high demand because of population increase and irrigation practices [7][22]. Planning and management of groundwater resources are greatly influenced by the increased demand for water. Therefore, it is necessary to monitor the groundwater levels and their Spatiotemporal variations to manage the resources in a better way for sustainable use [6]. While on the other hand if we talk about good drilling and piezometric wells estimation is a time-consuming process and costly [14]. So, to better understand the water levels in unsampled locations the estimation of water levels through spatiotemporal techniques is quite easy and feasible.

Geostatistical and deterministic data interpolations can give estimates of groundwater levels at unsampled locations [21]. These interpolation methods work differently but with similar rules of autocorrelation. So, it is important to choose the correct spatial interpolation technique for groundwater data estimation. There are two types of groups of approaches to determining groundwater levels. These approaches are deterministic and stochastic. Both Inverse Distance Weighting (IDW) and Radial Basis Function (RBF) are deterministic approaches where IDW works on the principle of creation of surfaces from distant points in reverse order from each measured point. While RBF on the other hand works based on the degree of smoothness in observed points. It is a deterministic approach that implies on functions of creating surfaces with help of the distance reverse method of each measured point without keeping in view any spatial relation among these points. While Radial Basis Function (RBF) is also a deterministic approach, this creates surfaces based on their degree of smoothing, and this approach has been able to determine the generalized space positions from various points [18][20]. While scientists used the kriging technique widely as this is used stochastic approach and used all the mathematical and stochastic properties of the data to develop a better understanding of the data points. Researchers around the world have used different interpolation techniques used OK and IDW techniques to reduce data redundancy at different locations of groundwater levels to reduce estimation costs as well. To get the improved and quality data studied OK method to optimize the groundwater level [16][21]. evaluated a variogram for estimations of groundwater levels by using the OK technique. In comparison, kriging cokriging gives more promising results in estimating groundwater levels [3][9]. Used the OK, IDW, and BRF techniques in their study and compared the interpose more results with observed data, and from these results, they evaluated that OK is a more suitable approach in their study area [20]. have studied different interpolation methods for groundwater evaluations, they have found that OK is the most suitable approach in the estimation of

groundwater depths in their study area [13]. have also used different stochastic interpolation approaches to compare the groundwater levels distribution spatially [23]. Arslan has also used OK, IDW, RBF, and COK interpolation techniques for groundwater level distributions spatially for estimation of seawater intrusion in coastal aquifers. have studied the OK, IDW, and BRF techniques for assessment of Electrical conductivity in paddy fields [19]. have studied the OK, IDW, RBF, and UK interpolation techniques to assess the accuracy of the spatial distribution of underground water levels [1][5]. studied different kriging techniques to assess the groundwater levels in the Arapahoe aquifer, results showed that kriging interpolation techniques can be best used where no data is available for estimations of groundwater levels [17]. have studied that OK and IDW techniques in the Islands of Singapore and they have mentioned that these interpolation techniques can be used for best estimations of groundwater levels spatial distributions [14].

The objective of our article is to compare the different interpolation methods i.e., IDW, OK, RBF for the estimation of groundwater levels spatial distribution in the aquifer of the Lahore division of Pakistan.

2. LITERATURE REVIEW

2.1 Study area and data collection

The Lahore division is the second largest division of Pakistan while the city of Lahore is the provincial capital of Punjab. Covering a total area of 4,528 mi² lying between 31°15′-31°45′ N and 74°01′-74°39′ E. From north to west Sheikhupura is surrounding Lahore, on east Wagha border with India, and in south Kasur district located. The river Ravi also flows on the northern side of Lahore. This area is totally groundwater dependent. The total population of the area is more than 1.280 m according to the 2017 Census.

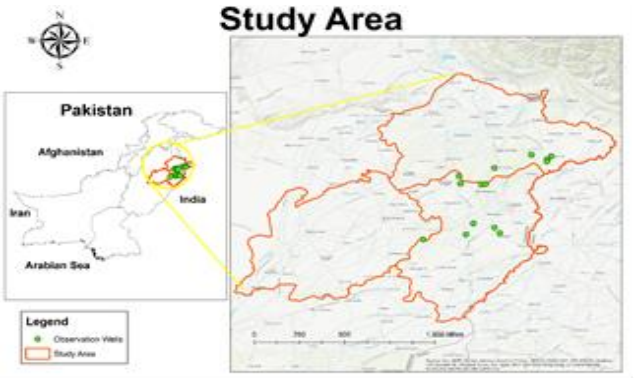

Fig. 1 Study area map

2.2. Climate, Geology, and hydrogeology

Temperature varies in both seasons from 34 degrees in June to 12 degrees in January. The region is semiarid with an average rainfall of 575mm/yr but this can be varied from 300-1200mm which contributes 40% of the groundwater recharge for the area. The study area is normally flat and at an altitude of 208-213m above sea level. Modern soils in the area are silt, clay, loamy clay, and sand. The aquifer is comprised of unconsolidated alluvial sediments.

Groundwater is mainly recharged by rainfall and River Ravi [11]. The products cultivated in the area are Wheat, Sugarcane, Rice, Jawar, Moong, Mash, Masoor, Maize, Oilseed, Mustard, Sunflower, Potato, Carrot, Cauliflower, Turnip, and fruits Orange, Guava, Mango, Lychee, Pomegranate, Java Plum, Peach, Date, and Banana. The groundwater in the area is mainly used for irrigation and domestic purposes but in recent years with an increase of population water is also used for industrial purposes.

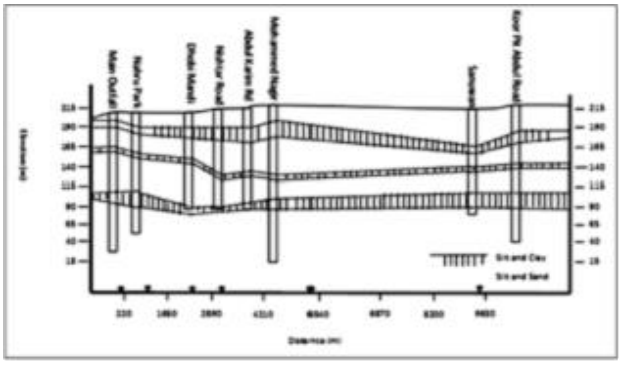

Fig. 2. Geological structure of the Lahore aquifer, Source: [12]

In this study area data from 14 wells drilled in different locations by irrigation department was collected for the period of 2003-2018 for two periods Pre-Moon Soon and Post-Moon Soon.

2.3 Methods

2.3.1 Weighting of Inverse Distance

The inverse distance weighting method is extensively used and is the simplest method in geosciences for the estimation of groundwater levels [15]. In this method, the values of the cell are obtained by a linear combination of weights datasets of sample points. Where weights denote the function of inverse distance. IDW is considered as the proportion of the correlation and similarity between neighbouring points and the distance between them. The surface in the meantime, which is being interpolated, represents a locally dependent variable. Hence the distance identified in IDW between two

points raised to the power of 2 which is the distance in between the two points from the exponent [14].

The mathematical model of the IDW is as follows.

$$z(x_0) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}} \quad (1)$$

Where $z(x_0)$ is interpolated value; n is the total number of values, x_i is the *ith* value of the sample, h_{ij} represents the distance between interpolated value and the sample data values, and β indicates the weighting power in Eq.1. IDW's estimation quality is highly affected by the power parameter β [4]. The size of the β power greatly affects the shape of the data samples. The greater the size or larger the β predicts that the closer points have a greater influence on predictions [2].

2.3.2 Ordinary Kriging

Ordinary kriging is one of the most frequently used methods in the interpolation of spatial data [8]. In this interpolation method the estimates are made at variable z at an ignored location point, these estimates are made based on the average weighted of variable z at adjacent observed points within the given area. The mathematical expression for this method is:

$$Z(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \quad (2)$$

Here x_i is the sample date point location, λ are the weights assigned to observed samples $\sum_{i=1}^{n} n\lambda_i = 1$. To provide an unbiased estimation the estimator sums unity to provide an unbiased estimation. For weights estimation the equation is as follows:

$$C = A^{-1} x b \quad (3)$$

A matrix of Semi variances between the data points

B vector of Semi variances between the data points and between the points where variable z is to be predicted

C Resulting weights [4] (Eq.3)

Ordinary kriging uses Semi variogram to quantify spatial dependence [24].

2.3.3 Radial Basis Function (RBF)

The value of RBF relies on the distance from the originating point or from the central value of any specific point. Which is real valued function. A function $\emptyset$ which satisfies the condition $\emptyset(X) = \emptyset(\| X \|)$ is a radial function. Radial basis function uses Euclidean distance, but other approaches are also possible [1]. RBF also avoid problems with not properly managed matrixes to determine coefficient, but the $\| X \|$ is always greater than zero. The most widely used RBF which is completely regularized spline.

CRS function is used in this study from all other four RBFs, often named as Thin Plate Spline (TPS), Spline with tension (SPT), Multi Quadric function (MQ) and Inverse Multi Quadric function (IMQ) [5][24].

2.4 Criteria for performance evaluation

In this study three different statistical interpolation methods were implemented to analyse the performance evaluation. For this the said measures were derived from the listed below formulas where Square Root (R^2), Root means square error (RMSE), and mean absolute error (MAE).

$$R^2 = 1 - \frac{ESS}{TSS} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum (z_i - z)}{n}} \quad (5)$$

$$MSE = \frac{\sum_{i=0}^{n} z - z_i}{n}, \quad (6)$$

Here:

ESS means "Error Sum Square" at ground water levels and

TSS means "Total Sum Square" at ground water levels.

Z_i and Z Predicts and observes values respectively.

n number of observations

All the statistical data was examined by running ME (Microsoft excel) and SPSS 16 (IBM, Armonk, NY, USA). The resulted prediction maps at ground water levels and all the other interpolation techniques analysed using software ArcGIS 10.5 (ESRI, Redlands, CA, USA). Below is the Flowchart of methodology is given in Fig. 3.

3. RESULTS AND DISCUSSION

3.1 Distribution of the spatial data

The Kolgomorove and Smirnov tests were performed to analyse the data and the normality of data. K-S test results has shown that data was not normal. To check this normality is important because according to probability theory normal data gives more reliable results [1].

As per the probability theory "Skewness" means distribution of the non-symmetrical probability of any attained random variables of real value. The values of Skewness outside of the range from -1 to +1 indicating a skewed distribution [10]. While "kurtosis" in the normal distribution is 0. Its value also varies from -1 to +1 in normal distribution. But in some cases, value from ± 2.0 is also acceptable. We performed distribution test and found out that data is not normal.

Table. 1: Statistical Values of the available data

Period	Min (m)	Max (m)	Mean	SD	Skewness	Kurtosis
Pre-Monsoon	11.7	29.8	17.5	5.3	1.686	2.214
Post-Monsoon	15.2	32.6	20.2	4.9	1.622	2.412

Table. 2: R2, RMSE, AME values for IDW, OK and RBF for pre and post monsoon season

Model	Training data			Validation data		
	R^2	RMSE	MAE	R^2	RMSE	MAE
Pre-Monsoon						
IDW-2	0.999	0.09	0.047	0.878	7.914	5.96
OK-Spher	0.481	3.439	2.26	0.121	7.691	6.23
RBF-CRS	0.999	0.337	0.16	0.942	8.184	6.06
RBF-SPT	0.997	0.713	0.38	0.389	8.163	5.73
Post-Monsoon						
IDW-2	0.951	2.694	2.51	0.886	9.596	6.86
OK-Spher	0.37	3.957	3.18	0.117	8.865	5.66
RBF-CRS	0.998	0.304	0.14	0.935	8.245	6.33
RBF-SPT	0.996	0.619	0.33	0.462	8.186	6.03

From three interpolations four different types of combinations were performed to evaluate the available data for the Pre and Post moon soon seasons for the period of 2003-2018. IDW was performed with the power value of 2 and neighbouring values 15,10 with circular vector type on groundwater level data. In OK method spherical OK (OK-Spher) variogram was selected for performance. To get the most suitable variogram sector type, lag values and search for neighbourhood the default values from GIS were selected. Where sector type was used is ellipse. Spherical model was used to be best fitted for predictions of groundwater levels in this study. In radial basis functions (RBF) method two mostly used functions Completely regularized function (CRF) and Spline with tension (SPT) were performed to predict the groundwater levels.

The maps obtained from interpolation methods for pre monsoon season for most and least fitted methods are shown in fig. IDW2 shows the least reliable results. Evaluation of these maps shows that the area where groundwater is present under 13.543m-15.219m is under area of lowest values 3.35km^2 while the highest value is 2km^2. While the area under 13.588m-14.740m where RBF-CRS performed the lowest area covered is 26km^2 and highest area cover is 2km^2.

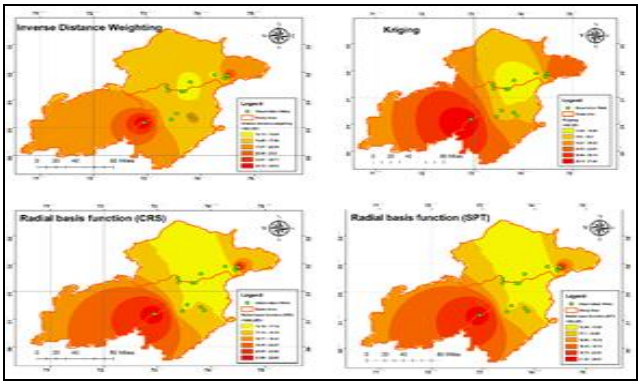

Fig. 3. Maps obtained from the interpolation methods of groundwater levels where (RBF-CRS) are most reliable indications and (IDW-2) least reliable.

The maps prepared for post monsoon season for RBF-CRS and IDW have shown in fig. Both maps are showing clear and distinct difference. Upon evaluation of these maps the lowest area calculated for IDW in between points 13.543m-15.219m is 9.25km^2 while the highest area is 6.47km^2. While the area calculated for RBF-CRS for points 15.361m-17.586m is 6.79km^2 and highest area is 1.49km^2.

3.2 Comparison of Interpolation Techniques

In the present study inverse distance weighting (IDW), ordinary kriging (OK) and radial basis function (RBF) interpolation methods were used to predict the groundwater levels. Where IDW with power 2, OK with spherical, and BRF with base functions of completely regularized spline (CRS) and spline with Tenison SPT were performed.

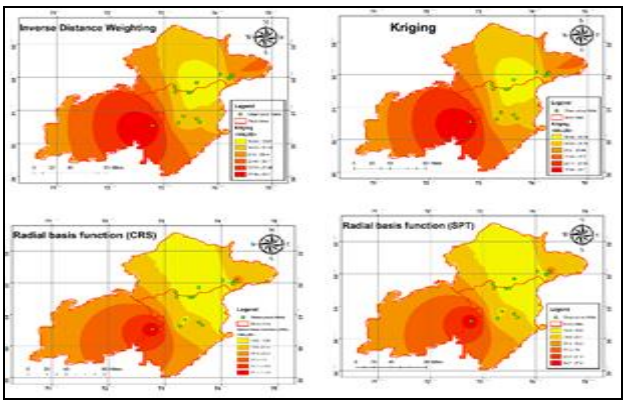

Fig. 4. Maps obtained from the interpolation methods of groundwater levels where (RBF-CRS) are the reliable indications and (IDW-2) least reliable

To compare different interpolation techniques R^2, RMSE and MAE were evaluated. All IDW methods were outperformed by OK variograms with higher values of R^2 and lower values of RMSE. While RBF-CRS method gives best fitted results than OK in evaluating groundwater levels. The highest value yielded for R^2 in RBF-CRS (0.942 and 0.999 for validation and Training data respectively for Pre monsoon while 0.935 and 0.998 for validation and training data respectively). The lowest RMSE for (Validation and Training data of pre monsoon is 8.184 and 0.337 respectively and for post monsoon it is 8.245 and 0.304 for validation and training data respectively for post monsoon period) also has similar findings [4][5].

The maps of groundwater obtained from interpolation methods have shown in fig.3. These are the least reliable maps of IDW and most reliable maps of RBF-CRS. These maps are showing the maps for post monsoon seasons are shown in fig.4. These maps are from IDW the least reliable and RBF-CRS the most reliable function. Maps showing clear differences in the groundwater level maps are showing that water levels are low due to overexploitation of groundwater for irrigation, domestic, and industrial use. Maps are showing that water levels are as low as (m) even in winter while it is considered the recharging season for groundwater.

5. CONCLUSION

For sustainable use of groundwater, it is necessary to predict the groundwater levels and their direction. As groundwater surveying and drilling is an expensive and time taking process so mapping groundwater is an advanced and easy technique to estimate the groundwater levels and from these estimations, one can easily predict the groundwater availability, quality, and where to drill a well for extraction of water. So, groundwater fluctuations mapping plays an important role in this process.

For this purposes groundwater level interpolation has been done with four different types of interpolations methods. These methods are IDW, OK, BRF-CRS and BRF-SPT, out of these methods OK and BRF outclassed IDW2 completely. While among BRF-CRS, BRF-SPT and OK BRF-CRS gives the most reliable results for spatial distribution of groundwater levels predictions. While IDW with parameter 2 gives the least reliable results for spatial distribution of groundwater levels.

Reasonable groundwater pumping is advisable in the study area. And there must be a balance between rainfall and pumping or recharging of the aquifer. The present study could be used to manage the watersheds in world for better management of groundwater resources. There must be a demand and supply balance among the water users if the area to avoid over exploitation and depletion of groundwater. This could be achieved through proper urban management, good water governance and policy.

6. DECLARATION OF INTEREST STATEMENT

The authors have no conflict of interest in manuscript writing and data publication.

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Microstructural Characterization of Mild Steel Used in Oil and Gas Pipeline

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***Abstract*—Results associated with microstructural and strength analyses of the material collected from the oil field are presented. The effects of varying microstructure and hardness by the heat treatment process were presented. The microstructural characterization and surface analysis were carried out by scanning electron microscope (SEM), Energy Dispersive Spectroscopy (EDS), X-ray Diffraction (XRD), and Rockwell for hardness analysis. The energy dispersive spectroscopy EDS indicated that the samples were in the range of low carbon steel (AISI 1008) i.e., highly ductile, and soft. XRD analysis showed that the Iron Carbide phase was formed during service conditions which is brittle in nature. Scanning electron microscopy SEM of the surface examination denotes that the material was greatly affected by erosion leading to crack initiation and propagation.**

***Keywords*—Low Carbon Steel, Corrosion, Microstructure, Hardness, Microscope**

1. INTRODUCTION

Mild or low-carbon steel is a very acceptable material due to its huge applications in industries. It provides good deformability due to its low yield strength, minimum cost, simplicity in fabrication and manufacturing, good strength, toughness, and weldability. Materials are being processed to convert it from high stable state to a lower stability by performing engineering processes to withstand harsh environment. Metals are unstable at ordinary environment and certain environment condition gives opportunities for these materials to combine chemically with elements to get stable state or lower energy state. Mild steel is one of the most usable materials in various production and chemical industries. However due to its high susceptibility to corrosion it deteriorates very rapidly as compared to other metals. Different strengthening mechanisms can be applied to enhance the grain refinement in order to increase the strength and toughness both simultaneously. Mild steel or low carbon steel consist of a small fraction of carbon that gives better plastic deformation behavior in sealing and leakage prevention. Mild or Low carbon steel are universally used for structural applications, food production industries, automotive and aircraft industries; however, its poor corrosion resistance at ambient atmosphere condition is a matter of serious concern [1][2]. All ferrous materials consist mainly of iron with small proportions of other alloying elements. These alloying elements have been added to obtain specific characteristics such as corrosion resistance, strength, and wear resistance to enhance the mechanical behavior of the resultant alloy. The most common steel alloying elements are aluminum, vanadium, nickel, manganese, molybdenum, chromium, tungsten, boron, and phosphorous.

Based on the carbon contents steel is divided into three major categories, low carbon, or mild steel wt. % 0.04-0.30, medium carbon steel wt.% 0.31-0.6, and high carbon steel wt.% 0.61-2.40. Increasing the carbon contents results in increasing the hardness of the materials and decrease in the ductility as well as corrosion resistance. High carbon steel can be used where hardness and strength is the first priority as in transporting, construction and relative motion between the parts, whereas mild steel can be appreciated in low cost and high ductile application environment. Despite the fact the low carbon or mild steel has high susceptibility to corrosion, is used in several applications in which corrosion phenomena is a key factor [3][4]. Many researches have been conducted to analyze the corrosion phenomenon of mild steel used in various industries. It has been investigated that the corrosion first initiates at grain boundaries and spread to the bulk of the grains. Statically evaluation of the material indicates that the inhibition of the materials has greatly affected the corrosion process [5][6].

Metallurgical factors are greatly affecting the corrosion rate. In practice, the characterization of the material determines the influence of grain size's structure and orientation on corrosion behavior. In oil and gas industries due to high temperatures and pressure the erosion-corrosion phenomena are greatly investigated. It is also investigated that sulfide inclusion in pure iron has also a marked tendency to react in a corrosive environment. Moreover, crystal structure and orientation also influence corrosion rate. The crystal structure is assumed to be perfect in three-dimensional spaces,

but in fact, there is variation in the arrangement of crystal which is considered as crystalline defects caused an exchange of electron and leads to electrochemical corrosion.

It is also indicated that the corrosion process has a great dependency on geotechnical characteristics of site, the presence of electrochemical corrodent and time of the materials [7]. The effect of inhibition of the materials to increase the corrosion resistance can be enhanced by applying suitable coating parameter time and temperature [8]. Moreover, the effect of different mixed inhabitant on the corrosion process of the mild steel, which leads to high increase polarization resistance. It is also concluded that the materials hardened by heat treated land recrystallization leads to increase the corrosion resistance [9][10]. The effect of zinc coating was studied, and it is concluded that zinc coating is a promising method of silane coating which is better inhabitant among the several inhabitant. It is investigated that the presence of several ferrous ions in the material can change the corrosion acceleration by one or more aspects [11][12][13]. The successful use of carbon steel line pipe relies on appropriate design allowances and corrosion controls. Carbon steel line pipe used in oil/gas production and transmission, is manufactured in accordance with American Petroleum Institute (API) specification 5L, does not have a closely specified elemental composition and microstructure. Consequently, it is fabricated to a set of mechanical requirements such as yield strength, tensile strength and fracture toughness. This can allow for significant variations in the elemental composition and microstructure, which can also influence corrosion performance. Although the specification emphasizes material strength and toughness, concentration limits of some elements (i.e., carbon, manganese, phosphorus and sulfur) are also specified to ensure weldability, formability and corrosion resistance. However, the levels of alloying elements such as nickel, chromium and niobium, which may be added to the steel, are not specified. Furthermore, permitted levels of carbon, manganese, phosphorus and sulfur, which are specified for each grade, may be different for seamless, welded and cold worked pipe. Similarly, the compositional and microstructural properties can vary significantly between pipes of the same grade from different manufacturers, and these variations may lead to substantial differences in the corrosion resistance of steel line pipe [14].

2. MATERIALS AND METHODS

2.1 Materials

Soft iron/Low carbon steel specimens were collected from Mari Gas oil field in the form of ring gasket as shown in Fig 1. The material in the ring gasket form which is used in oil and gas production pipeline between the flanges groves to seal the surface to prevent leakage. Mostly the ring gaskets are formed from soft material to flow in the groves easily when joint the two flanges by nut and bolt.

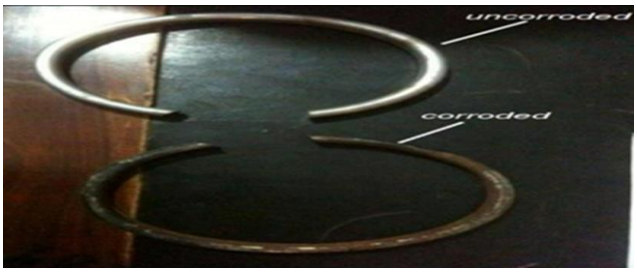

Fig. 1. Corroded and uncorroded ring gasket collected from Mari gas oil field

2.2 Experimental Setup

Samples are prepared from both corroded and uncorroded materials for SEM analysis. The total numbers of samples (corroded and uncorroded) were 16, of which 8 samples are corroded and, 8 samples of uncorroded material. A special cutting machine was used to cut the sample of specified dimensions carefully so that not overheat to damage the grain size and shape as shown in Fig 2(a). All the samples were mounted in backlit as shown in Fig 2(b) and polished with 9-micron diamond paste and nylon cloth. As the samples prepared free from scratches and obtained a mirror-like surface, then carefully break the mounted and etched in two different Nital solutions. The two Nital solutions were based on the concentration of nitric acid (HNO_3) in ethanol (C_2H_5O). The two etchants contain 8% Nitric acid in ethanol and the second 3% Nitric acid in ethanol. The polished samples were etched in two ways to get good and visible grains i.e., some samples were etched for 15, 30, 45, 60 and 90 seconds in Nital containing 3% nitric acid while others were etched for a fixed interval of 60s in Nital containing 8% Nitric acid in Ethanol.

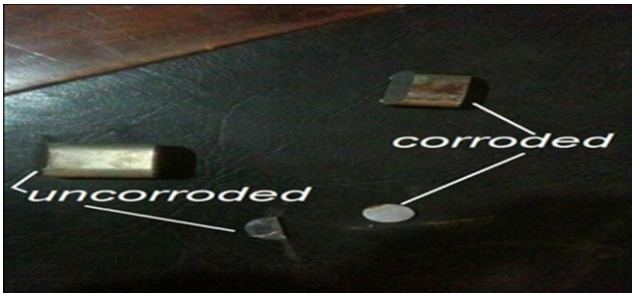

Fig. 2a. Cut samples of required dimensions

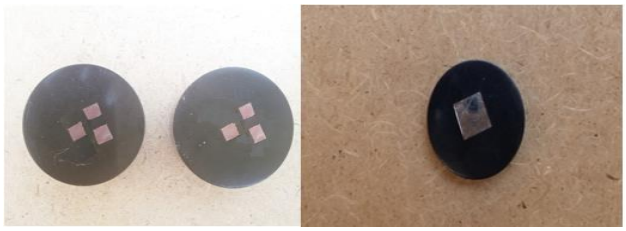

Fig. 2b. Samples are mounted in backlit for polishing

3. RESULTS AND DISCUSSION

3.1 SEM Analysis

A SEM analyzer was used to investigate the microstructure with a JEM-5910 JEOL analyzer. The SEM analysis of the uncorroded sample in 3% HNO_3 in ethanol are obtained at 200X. Samples etched for 30 sec revealed the granular structure as shown in Fig 3, the same solution and procedure is applied for corroded sample gives the granular structure as shown in Fig 4. The samples over etched for longer than 30 sec in 8% Nital solution. But as the sample etched in the accurate Nital solution and time i.e., 8% and 30 sec or 3% and 60 sec, a more visible structure obtained. According to the lever rule low carbon steel AISI 1008 contains 97.4% Ferrite α and 2.6% cementite FeC_3. Only Ferrite could be observed due to its relatively higher concentration in the examined sample which had two phase BCC crystal structure as shown in Fig 5. Moreover, it is clearly observed from Fig 5, that the pearlitic area is increases strongly after corrosion, this is due to the inclusion of carbon exist in crude oil under high temperature and pressure. As the carbon is absorbed under high temperature and pressure a chemical segregation effect is initiated in which a specific phase precipitated on the grain boundaries. The phase containing high percentage of iron sulfide FeS as observed in Fig 6.

The attack is usually related to the segregation of specific phase formed on grain boundaries. Corrosion then occurred by preferential attack on the grain boundaries, makes the grain boundaries weaker. As the grain boundaries is affected by corrosion and make it weaker so there is high temperature and pressure, and crack is initiated and propagated towards the bulk of the grain as indicated in Fig 7.

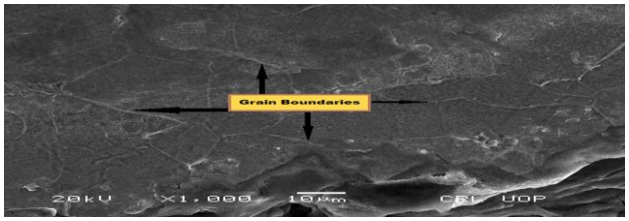

Fig. 3. Microstructure of uncorroded samples obtained by SEM analysis

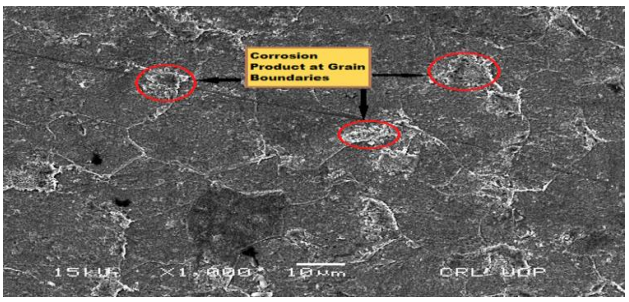

Fig. 4. Microstructure of corroded samples obtained by SEM analysis

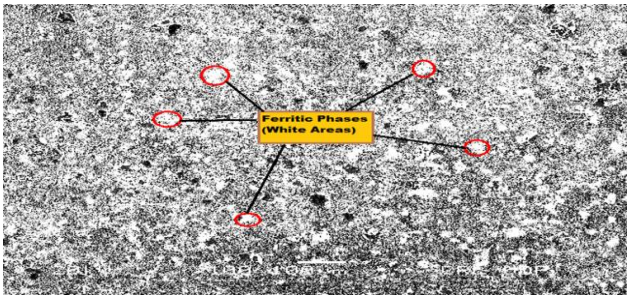

Fig. 5. SEM analysis of uncorroded samples shown ferritic structure

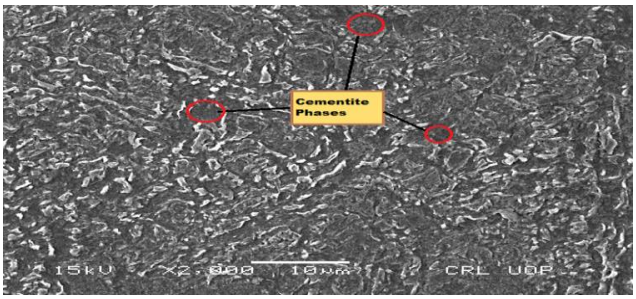

Fig. 6. SEM analysis of corroded samples shown cementite structure

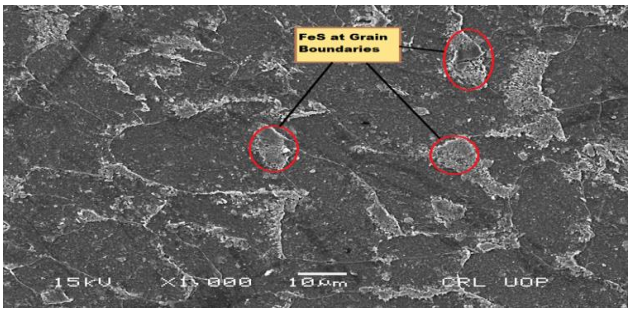

Fig. 7. SEM analysis of corroded sample in which FeS precipitate on grain boundaries.

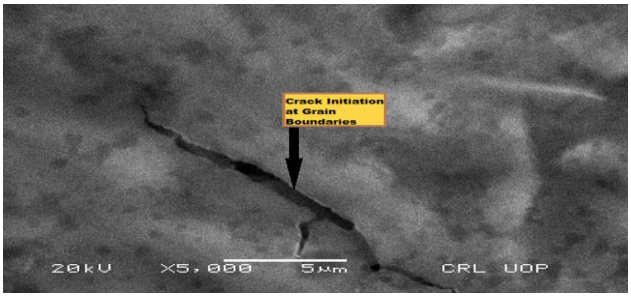

Fig. 8. Crack initiation and propagation at grain boundaries after corrosion

3.2 X-Ray Diffraction

The X-Ray test was used to find out the corrosion product. The maximum corrosion product was containing iron sulfide shown in Fig 9. The corrosion product contains α-FeOOH, γ-FeOOH and amorphous-like phase and the amorphous like phase contains more than 50% of the rust. The thickness of the rust is uneven showing wavy and undulating near the surface of the steel and rust the amorphous phase takes place.

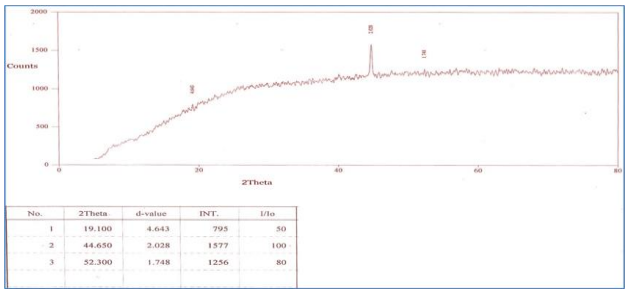

Fig. 9. X-Ray analysis of the corrosion product

3.3 EDS Analysis

Elemental composition of the material were determined by energy dispersive spectroscopic analysis of both the materials i.e. corroded and uncorroded were very similar as shown in Fig 8 and Fig 9 respectively. The chemical composition is of the material is summarized in Table 1. Only a minor change was observed in oxygen. This is due to the carbon dioxide present in the crude oil which results of the chemical reaction of carbon with the water in the presence of high temperature and pressure.

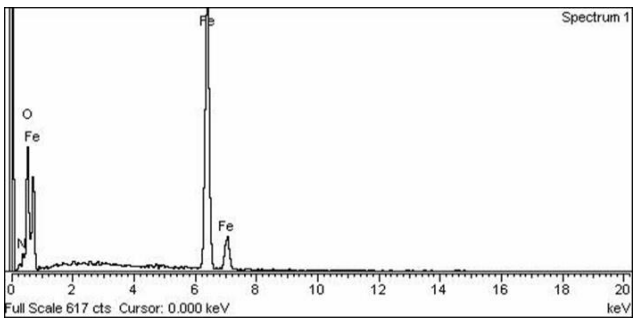

Fig. 10. EDS analysis of the samples before corrosion

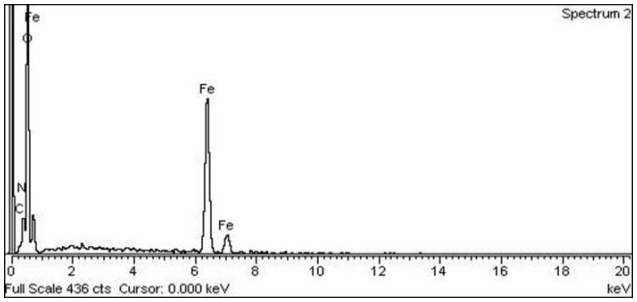

Fig. 9. EDS analysis of the samples after corrosion

Table. 1: Chemical composition of the material

Material	Composition %
F	89.8
C	0.96
Mn	0.68
P	0.18
S	0.01
N	8.37

4. CONCLUSION

This study has shown that the corrosion occurred in a chemically harsh and aqueous medium in the crude oil. First chemical corrosion takes place and then initiated by the high velocity of crude oil leads to erosion-corrosion. Furthermore, mild steel ring gasket investigated in this paper revealed corrosion phenomena variations due to the variation of environment in which the material was used. It has been shown that variations in the corrosion/penetration rate occur partly due to differences in the microstructure. It was found that steels with a banded ferrite/pearlite structure perform poorly in terms of localized corrosion, and this was attributed to a segregated distribution of the iron carbide phase cementite (Fe_3C). By contrast, all other microstructural types were observed to have a uniform distribution of cementite. Insignificant differences were observed in the corrosion performance of steels having fine-grained ferrite, ferrite /coarser and somewhat acicular pearlite /pearlite, or tempered martensite microstructures. In any event, the ferrite /coarser and somewhat acicular pearlite /pearlite material performed better in terms of both the average corrosion and penetration rates. It is suggested that a ferrite /coarser and somewhat acicular pearlite /pearlite structure may be more suitable under the conditions investigated in this study compared to a coarse banded ferrite/pearlite structure. This paper has demonstrated that steel microstructure is an important consideration when selecting a ring gasket material for a particular application.

5. DECLARATION OF INTEREST STATEMENT

The authors have no conflict of interest in manuscript writing and data publication.

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Design and Modification of Arduino-Based Rocker Bogie Mechanism for Security Purposes

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***Abstract*—The suspension system of the rocker-bogie allows the robot to overcome an obstacle, such as a rock, while the system remains stable on the ground. The linear motion of the bogie of our six-wheeled walker bogie protects the entire system from rollover during high-speed operation. This improvement will increase the reliability of the structure on rough ground and allow faster exploration. Pro E is used in this case to simulate the rocker-bogie suspension mechanism. Our goal is to mimic the rover to detect slippage and deviation from the target path. Experimental results will prove the validity of the models. We will increase the number of support polygons to make the system more stable and flexible at high speeds, while maintaining its original robustness to model and analyze the rover bogie system with improved system stability and operating speed. Several mechanical adjustments are made to the system and suggestions are made to maximize the utility and stability for future operating speeds of the rover.**

***Keywords*—Arduino-Based, Rocker Bogie, Security Purposes**

1. INTRODUCTION

The Rover Bogie mechanism does not use springs and has short parts for each wheel, allowing the chassis to climb over obstacles such as rocks, ditches, sand, etc. These obstacles can quadruple the diameter of the wheels while ensuring that all wheels stay on the ground as long as possible. As with any suspension system, the height of the center of gravity determines the tipping stability, and the recommended solution is the same. As the load side yields during obstacle running, spring-based systems tend to tip.

Any vehicle equipped with a rocker chassis can withstand a tilt of at least 450° in either direction without tipping over, which is the most important advantage for any heavy vehicle. When large hurdles are in the way, the system is designed for use in low-speed work vehicles (e.g., heavy truck dozers) moving at a slow pace of about 12cm/s to avoid dynamic shocks and damage to vehicle equipment. The technology allows the climbing barrier to have a diameter twice that of the wheel. No springs or steering knuckles are used.

Threats to our security are increasing as technology advances. In this project, we seek to develop, simulate, and evaluate a technique (side channel analysis) that can detect metal and be used for security purposes.

There is an increasing demand for mobile robots that can operate in an unstructured environment with highly uneven terrain. Such robots are used to perform hazardous tasks that cannot be performed by humans. Mobility robots that walk on any terrain differ from normal mobile robots in that they consider the effects of unstructured terrain and its environment [1]. These robots are eventually built to operate efficiently on natural terrain that may be steep, rough, or deformable, and they are used in fields such as space exploration, security and rescue, and military and civilian applications [2][3][4][5] [6][7][8][9].

Sojourner is the first Mars rover to use rocking landing gear technology. One of these moving systems is now the type of suspension chosen by NASA for the rover [9]. The rocker arm is the most important link. The differential mechanism connects all links and the chassis of the robot. The bogie link pivots one end of the rocker while the other supports a wheel. Each end of the bogie connections has wheels. The Rocker Bogie's suspension system allows a six-wheeled vehicle to maintain contact with the ground with all six wheels, even when traveling over very rough terrain. This feature offers two major advantages. The first advantage is that the pressure on the ground is more evenly distributed. This is especially important in soft terrain, where heavy ground pressure could force the robot to sink into the surface. Second, when the vehicle travels over steep or uneven terrain, all six wheels remain nominally in contact with the surface and under load, making it easier for the vehicle to navigate such terrain. Kumar and colleagues [10] presented a low-cost rocker-bogie linkage rover. The mechanism

can traverse different surfaces, and the left and right rockers can each traverse different obstacles. In addition, the rover can withstand a slope of more than 50 degrees without tipping to the side. In another study, a Rocker-Bogie Earth Exploration Rover (R-BEAR) was designed based on JPL's Sojourner [11][12]. However, the purpose was to explore the Earth and not Mars. According to the results of the study, the manufactured prototype is more stable when moving on hard and sloping terrain. However, it does not work well on soft surfaces such as grass and sand. It was also found that numerous sensor feedbacks and mechanical constraints were not considered in the experimental results. Wang proposed the Martin rover to solve the problem of dynamic instability in hard terrain. This rover has a modified rocker-bogie suspension system that works in many modes. When the terrain is an apartment, it can increase the span of the rocker-bogie support polygon to increase the driving speed, but when the terrain is rough, it can return to its original shape and slow down [13]. The Argo, which is similar in design to the Martin Rover, has been further improved. The difference is that the algorithm developed dynamically changes the angular velocity, traction, and acceleration of each wheel based on performance. The problem of dynamic instability in terms of lifting the wheels when crossing different obstacles with different wheels was partially solved by implementing this algorithm [14].

2. BACKGROUND AND LITERATURE

2.1 Background

Robots are constantly being integrated into numerous fields to relieve humans of heavy and painful tasks. They are currently used in offices, the military, medicine, industrial automation, planetary exploration, security systems, hazardous areas, and agriculture [1]. The planned design of the robot will allow it to move through regions and locations that are inaccessible to humans. The rover can be used for research, surveillance, and rescue purposes. The robot is designed to go to places with little damage and assist humans. Even robots can fly at high speed on apartment surfaces and garbage. The robot will be equipped with a video camera. The robot will search for regions that are inaccessible to humans. To explore the planet, the rover will be able to walk and live in harsh environments, as well as collecting dust and rock samples through manipulations installed on top. Bluetooth wireless support will be provided by the robot. The communication is done by setting up the communication. We use an Arduino UNO as the microcontroller and the HC05 Bluetooth model to communicate with the user in this design. No remote control can match the dexterity of a human hand. Manipulation here is accomplished with the ease of human hand gestures along with the rover without relying on standard remote controls that require specialized and professional operators.

2.2 History of Rocker Bogie

Thomas Thueer presented the Crab locomotion concept and compared it to existing rovers in terms of obstacle-overcoming capability. Similarly, Harjinder Singh, described the design, development, and testing of a six-wheeled lunar rover capable of traversing difficult terrain. The suspension mechanism of the rover was developed using the Rocker Bogie mechanism. The Rocker Bogie mechanism was studied and simulated in [1][2][3].

In this study, the rocker bogie actuation system was used for metal identification and safety purposes. Pro-E was used for model design and Proteus was used to simulate the rocker-bogie rover walking mechanism, which can be used for safety and mine detection. In our software-based design, we incorporated a solar system for power, a sensor for metal identification, adjustable articulated wheels for rock climbing, an Arduino Mega for the microcontroller, and a camera for image capture and data acquisition.

2.3 Measurement of Percolation Rate

2.3.1 Lunakhod

The first system selected was the geological reconnaissance vehicle "Lunakhod", which was sent twice by the Soviet Union. Luna's mission is to gather information and provide images of the city's surroundings. At the Deep Space Center near Moscow 5 in the Soviet Union, a team of five instructed Lunakhod in real-time. Lunakhod 2 visited the Lunar Med (Rainy Sea) memory bank for 11 months in one month, covering 37 kilometers of the lunar surface.

2.3.2 Sojourner

NASA -Jet Propulsion Laboratory and California in 1996. the Institute of Technology has developed a better rover. Sojourner and Marie Curie are two similar designs. The smaller rover weighs only 10.5 kg and is equipped with a microwave oven. The large rover was installed in December 1996 with the Sojourner Pathfinder lander. I have a Curry Rover. It is also scheduled to be sent to Mars with the 2001 mission “cancelation.” Operators issued commands

via the Pathfinder lander and monitored the rock and soil composition of Mars for three months. Susan (Suzanne) is a breakthrough in the search rover because of its unusual six-wheel suspension arrangement. A half-wheel diameter can regulate the height of the diameter to overcome obstacles such as tables that hinder the vehicle.

2.3.3 Nano rover

The Nano Rover is the other rover in the active suspension system. It is designed to search for small celestial bodies such as comets and humans in space. Features and benefits of this compact, lightweight robot. The system consists of four wheels with a diameter of 6 cm. The wheels are individually positioned on the positioning struts of the chassis. Tipping over is not a problem, as the robot can go left and right (upside down). The on-board computer can also use the suspension system to adjust the traction.

2.3.4 Shrimp

The Swiss Federal Institute of Technology also designed Crab, a walker on six wheels. Climbing an obstacle four times the diameter in front of two wheels, one of the EPFL has no stability problems. The eastern wheel includes four parallel colored bogies that balance the reaction force of the wheels throughout the climb. Motors drive the individual front and rear wheels, which are directly connected to the main body and increase the climbing ability.

2.3.5 Inflatable Rover

Another option is to walk over obstacles in challenging environments with larger wheels that can easily handle the roughest tasks. The rover identified by the Rocky Surface Probe is 1.5, and the diameter of the instrument wheel allows it to cover about 99% of the surface. The inflatable rover has three wheels driven by motors.

2.4 Recent Rovers and their missions

Most space exploration activities fall into three categories: an interest in better understanding our universe; an interest in better understanding our universe; and the economic potential of exploiting alien natural resources; our planet; and the bodies of future alien colonies; and our scientists are most interested in Mars. This is because the bodies of these planets are spherical and lie close together.

The fluid environment is quite inviting, and another hue might exist. The Moon is too large to be used for scientific equipment such as observatories or infrared binoculars because it has no atmosphere. These devices can measure the signal that would otherwise interfere with or destroy the Earth. Most of our knowledge about Mars relates to the planet's growth, particularly its potential for human settlement. Discover more about its structure. Mars' atmosphere and soil can shed light on whether or not the planet harbors microbial life. Since 1976, the National Aeronautics and Space Administration (NASA) has been exploring the surface of Mars since the tandem landings of the Viking 1 and Viking 2 landers. The Mars Pathfinder (MPF) lander successfully delivered a Sojourner horizontal rover in 1997. NASA hastily launched two Mars probes, Soul and Space, in 2004. Although NASA sent numerous rovers to Mars in November 2011, the Mars Science Laboratory (MSL) launched by NASA was named "Rover Curiosity," and each mission had the same purpose.

2.5 Design and optimization of Mars Rover's rocker bogie mechanism

The Rocker Bogie suspension system was developed specifically for space probes. It looks back on a long history of development. The term "rocking bogie" refers to the awkward stage of maturity. Fig. 1, shows the linkages, which are all parts of the suspension system and are balanced in Phuket, as these rockers are connected to each other and to the vehicle chassis by certain upgrades. Keep the center of gravity of the entire vehicle in line with the movement. If one of the rocking chairs lifts, the other will fall. The chassis that allows the two joysticks to move in unison is critical to maintaining the average tilt angle of the two joysticks. One end of the tilt lever is equipped with a drive wheel with s, while the other end can be pivoted, according to the precise design. A Phuket that provides the necessary movement and freedom. Responds to the suspension system of the rocker bogie.

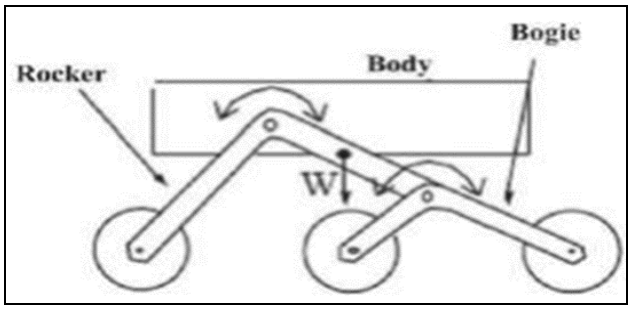


Fig. 1. Rocker bogie mechanism of rover

3. METHODOLOGY

Rover owes its mobility to the rocker-bogie mechanism. Rover rides in a six-wheeled teeter-totter buggy. The suspension mechanism keeps the wheels in place and allows Rover to negotiate obstacles. Each wheel is powered by its own electric

motor. The vehicle whirls, spins, and flings the altar around. A rover can withstand a 45-degree tilt in any direction without turning back. The rover is controlled wirelessly, and the architecture is shown in Fig. 2. The signal is supplied by a smartphone connected to the Arduino via software.

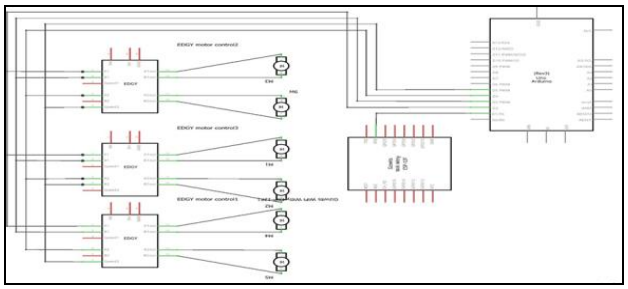


Fig. 2. Circuit diagram of rover

3.1 Working Mechanism

Arduino (IDE) is a cross-platform application developed in C and C^{++} functions for Windows, MACOS and Linux. The Arduino IDE includes a software library from the Wiring project that supports a variety of standard input and output processes. The open source software (IDE) for Arduino makes it easy to create code and load it onto the development board. It is compatible with Windows, Mac OS X and Linux. The programming is written in Java and is based on open source applications like Processing. The software is compatible with any Arduino board. The specifications for the hardware are the Arduino UNO, the L293d motor drive, the Node MCU, the V380 camera and the metal detector, which are all part of the same system, as shown in Fig. 3.

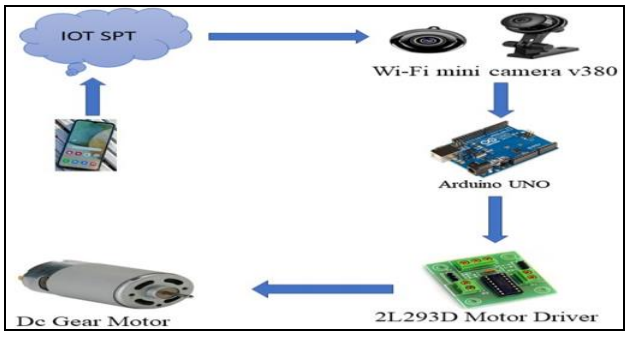


Fig. 3. Block diagram showing working mechanism of rover

The Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital inputs/outputs, 6 analog inputs, a 16 MHz ceramic resonator (CSTC 16160055-R0) and a U A SB connector, a power connector, an ICSP connector, and a reset button. It contains everything you need to support the microcontroller. To get started, connect it to your computer with a USB cable or power it up with a AC adapter or battery. You can play around with Ono regardless of whether something is wrong. Worst case scenario, you can replace the chip and reboot for a few dollars.

Uno, which means one in Italian, was chosen for the release of Arduino Software (IDE) 1.0. The Arduino Uno board and Arduino software version 1.0 (IDE) were reference versions of Arduino, now intended for new releases. In the series of Arduino USB boards, the Onboard is the first and reference model of the Arduino platform. The Arduino Board Index contains a complete collection of current, historical and obsolete boards. The L293D motor driver is offered to provide a user-friendly interface for embedded programs and to provide a user-friendly interface for the user. The L293D motor driver is installed on a high quality disposable non-PTHPCB. The pins of the L293D motor driver IC are connected to the connectors to allow easy access to the functions of the driver IC. The L293D is a dual bridge driver. It can power two DC motors, relays, solenoids and other devices. The device is TTL compatible. The two H-bridges of the L293D can be connected in parallel to increase the current capacity to 2A. This L293D module can drive two DC motors in either direction. Features Easily adaptable to any system, motor supported in external power supply for motors, P-level PWM (pulse width modulation) selector switch, 2-pin terminal blocks for easy motor connection (Phoenix connector) and H-bridge basic motor driver IC (L293D) on board. This is a module designed exclusively for metal detection. The module generates and responds to currents when metal objects are encountered. A nice buzzer signals the system when it detects an object and allows the ship's potentiometer to be adjusted.

Metal Detector The power supply leads for the non-contact metal induction module must be soldered on for the module to work. The positive terminal is on the outside of the module, the negative terminal is between the potentiometer and the electrolytic capacitor.

The model of the Rover Cad is shown in Fig. 4. It is a 12 VDC, 100 rpm motor driven by an L293D motor driver. The Rover is driven by six wheels, so six DC motors are needed. 360° cameras with HD 1080P quality and 360° fish lenses provide the visual view. Multiple view modes, easy zooming and focusing on small details, ideal for monitoring vacation homes, pets, businesses and elderly 2. 4G Wireless Wi-Fi Mobile Remote Our user manual will guide you through every step. And take a look at the camera in 1 minute. Widely used for indoor and outdoor: baby monitor talk and listen remotely

via mobile app. You can stay in touch with your baby when you lost him and want to talk to him. This home security camera provides a fantastic nighttime experience, even in depth, and complete security to monitor all rooms at night. "Daylight is not just a limited view of the light at any time of the day or night.

MIT App Creator is an intuitive visual programming environment that allows everyone (even children) to create fully functional applications for smartphones and tablets. For those MIT application developers, the first application for these novices is easy and can run in less than 30 minutes. Moreover, compared with traditional programming environments, our block chain tools can facilitate the creation of complex, high-impact applications in less time.

The MIT Applied Innovation Project aims to democratize software development by empowering everyone, especially young people, to move from technology consumption to technology creation. In this project, we can create an app to easily control our robot from anywhere. The design of the app is user-friendly and simple so that anyone can easily understand it and control the robot. The user interface is shown in Fig. 5.

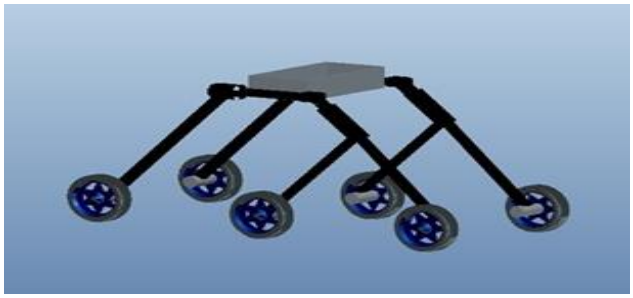


Fig. 4. Rover CAD model

Fig. 5. Controller Interface

The prototype of rover is shown in Fig. 6. The rocker bogie mechanism is responsible for its movement. The rover mounted a six-wheeled rocker bogie suspension system that ensures the wheels stay in driving in a specific area and allows the rover to overcome obstacles. Each wheel has its own motor. The car revolves around the entire space, and the savers and curves turn the altar. The rover is designed to withstand a 45-degree tilt in any direction without rotating. The rover is controlled wirelessly, and the signal is transmitted to Arduino via software using a remote control from mobile phone.

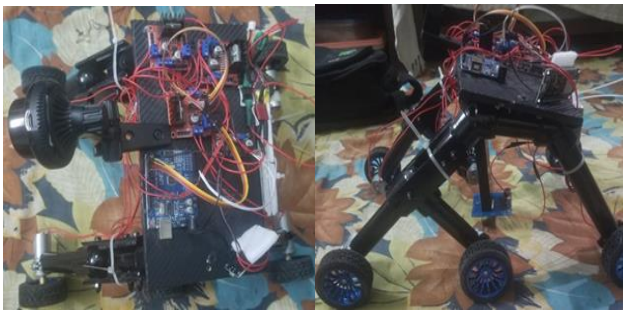


Fig. 6. Rover prototype

3.2 Experimental Evaluation of prototype

3.2.1 Case 1: Testing of Rover at inclined surface

Fig. 7 a, b and c shows that our proposed design can easily climb the inclination angle ranging from 45 to 60°. At 65° the rover cannot move because it cannot create that much thrust which results the rover rollover. Considering the stability aspect, the rover while moving on inclined path, whole set of wheels of rover has contact with ground. This also proves the fact that this rocker bogie can beneficial for rough terrain.

Fig.7. Rover going through rough and step terrain

3.2.2 Case 2: Testing of rover on wet surfaces

Fig. 8 a, b, and c, depicts the movement of rover on an uneven surface. This rover is tested in laboratory section of mechanical engineering department. It has been evaluated that the proposed design can move on soft surface like wet soil without getting stuck in the voids present in the soil. This is possible because of the continuous wheel's traction

support that provides thrust to augment the rover on soft surfaces.

Fig. 8. Rover moving on rough and wet surfaces

3.2.3 Case 3: Testing the rover while moving on rough terrain

Fig. 9 a, b, and c Developed prototype has the ability to comfortably move on sand, gravels and wet soil without getting stuck in the voids. This is possible due the mechanism of the rover in which the thrust force of wheels supports the body to move on sand or soft soil.

Fig. 9. Rover moving on rough and soft terrain

3.2.4 Case 4: Evaluation the climbing action of rover

Fig. 10 a, and b, shows that the rover can overcome the obstacles at step surfaces. From the test our proposed suspension system can easily climb our obstacles, due to the free movement of bogie while moving on obstacle can help the rover to climb easily.

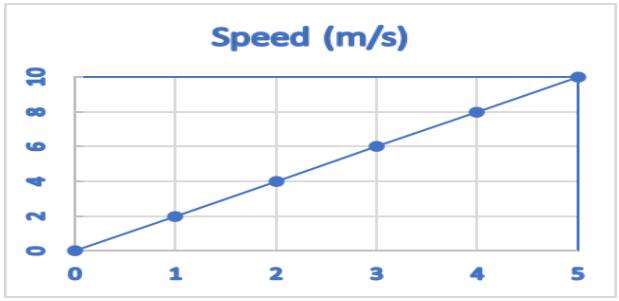
Fig. 10. climbing action of rover

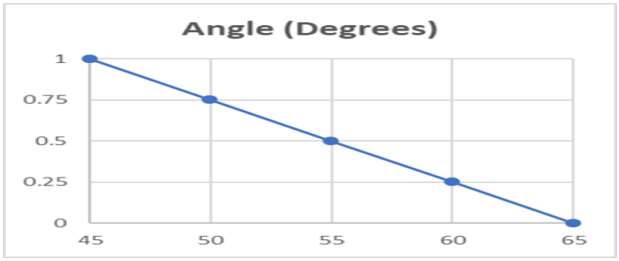
4. RESULTS AND DISCUSSION

With some height increase in angle can clearly show that, at 45 degrees and 1m height the speed is maximum and with the increase in height more thrust force will be required hence causes gradually decrease in speed of the rover. At 65 degrees angle the rover cannot move, because it cannot create the thrust force required to climb such heights as a result the rover rollover.

Time (seconds)	Speed (m/s)
0sec	0m/s
2sec	1m/s
4sec	2m/s
6sec	3m/s
8sec	4m/s
10sec	5m/s

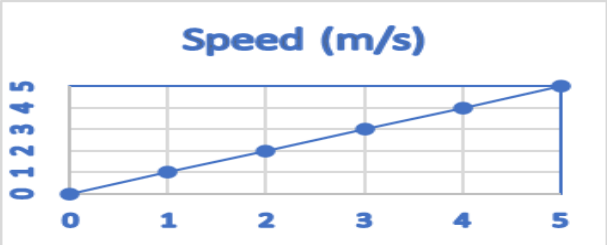
Time (seconds)	Speed (m/s)
0sec	0m/s
1sec	1m/s
2sec	2m/s
3sec	3m/s
4sec	4m/s
6sec	5m/s





The above graph shows that for a rover moving on wet surface will require more thrust force which in result will cover less area and will take more time

(here speed of the rover will be half as compare to dry surface).



The graph gives us straight line when the rover is moving on dry surface. The speed is not effected by the surface, additionally, it can conveniently move on it without any disturbances and can cover maximum distance in less time.

5. CONCLUSION

With the continuous development of alien reconnaissance rover technology, this kind of robotic technology can also be seen as a potential application on earth. Its real-time video monitoring and feedback capabilities can help you detect various threats where people cannot be accessed. Due to its compact design, it can be used in military and defense fields. In the near future, dance, rehabilitation, measurement, risk management, etc. can change the demand for human needs. This technology has unlimited possibilities and can be used in various applications.

6. FUTURE WORKS

The mobile station built by this project is specifically designed to support future work as a modular research platform. The rover may be used more effectively as technology advances, with high resolution cameras attached, and the prototype has been evolving on a small scale. Some progress has been achieved, such as attaching a defensive system to the rover that bomb disposal personnel can use to explode bombs. It can be utilised to carry people and items through rough terrain or obstacle-like impediments as larger models are developed. This technology can be used to supplement the wheelchair. The prototype can be brought to tough terrain such as an agricultural area, a forest, or a valley.

7. DECLARATION OF INTEREST STATEMENT

The authors have no conflict of interest in manuscript writing and data publication.

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Design and Analysis of 11-level Cascaded H-Bridge Multilevel Inverter using Various SPWM Controlling Techniques Considering Current and Voltage Harmonic

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***Abstract*—This paper implements an 11-level Cascaded H-Bridge multilevel inverter using Simulink /MATLAB. The output voltage and current of the inverter are analyzed in detail by considering IPD-SPWM, APOD-SPWM, and POD-SPWM. The effect of modulation index, RL load variations, and passive low pass filter has also been demonstrated. Simulation results suggest that a higher value of modulation index undergoes less Total Harmonic Distortion (THD) and harmonics in the current waveform are highly reduced to 4.42% if RL load is used which qualifies for IEEE standard-519, However, harmonics in voltage can be mitigated using low pass filter. In the end, we propose POD-SPWM be the best candidate among the three SPWM techniques.**

***Keywords*—Multilevel, THD, APOD, POD, SPWM, IPD**

1. INTRODUCTION

The inverter works as a bridge between DC sources to AC Networks. Any photovoltaic cells or a simple battery can work as the DC source. Though inverters can be categorized into many types based on output waveform, voltage, current levels, and switches placements. However, mostly its two types are considered: Half-Bridge with two switches and Full-Bridge with four switches. Half bridge undergoes higher THD of 48.34% while Full Bridge with quite less as a result later is always preferred over the previous [1][2].

Appliances like Speed drives, printers, telecommunication equipment, and many other appliances demand high-quality power which requires the output of an inverter purely sinusoidal. The purity of any waveform can be easily determined by THD (Total Harmonic Distortion) [3]. As per IEEE standards, the output THD of any system should not exceed 5% as far as the optimum delivery of power is concerned [4][5]. To cater to such demands, multilevel inverters are highly recommended in the literature review [6][7][8]. The small steps in output waveform make such inverter topology produce better common mode voltage,high electromagnetic compatibility, reduced switching losses, and less THD [9].

Based on how they use DC sources, multilevel inverters have been divided into different categories. Diode-clamped inverters and flying capacitors utilize common DC sources while cascaded inverters utilize separate DC sources. Inverter clamped inverter multiple capacitors are placed in series which are fed by different phases with multiple voltage levels using diodes The diode only transfers a little amount of voltage, which lessens the strain that voltage puts on electrical equipment. This inverter's output voltage, which is only half as high as the input voltage, is its primary flaw. Flying capacitor inverter contains condensers. Capacitors are connected in series. However, switching states remain the same as in the diode-clamped inverter. The drawback of such an inverter is its low output as compared to input voltage [10][11]. Multilevel cascaded H-bridge inverters have been the key subject for researchers in the last several years [12][13]. With different input DC voltage levels, this inverter creates the desired output voltage [14].

2. CONTROL STRATEGIES

For various multilevel inverter topologies, numerous modulation approaches have been developed. The performance of the controlling technique must be linked with producing waveform with less harmonic distortion. These techniques also help multilevel inverters to attain more output levels without reducing power. Various PWM techniques are implemented in [15][16][17]. Carrier-based PWM controlling technique is highly recommended in the literature, especially for industrial applications. This utilizes phase or level parameters to limit the current and voltage harmonics [18][19][20]. Whereas Space

Vector Modulation is also a good alternative which is implemented on a three-level inverter [21].

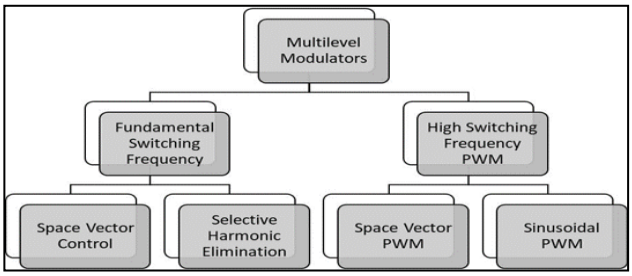

Fig. 1. Classification of various multilevel controlling methods

Pulse width modulation is the technique through which we can control the conduction of switches used in inverters. Theoretically, the Pulse takes zero time for rise and fall. This makes PWM a versatile and efficient technique to control power electronic switches. In this technique, the duty cycle of the pulse is varied to control the conduction of the switch. The PWM method is used in various applications ranging from variable speed drives to controlling the conduction of semiconductor switches to achieve the intended output pattern of voltage or current [22]. The duty cycle is calculated using Eq. 1.

$$D \propto PW \quad (1)$$

It is clear from fig. 10 that D=25% depicts the conduction will be one-fourth of the period; however, if the value becomes $D=2^8-1=255$ then the switch remains closed for whole the time. Various types of PWM techniques are proposed for different invert topologies [23]. It is clear from the literature review that no PWM technique is suitable for all topologies however the specific technique is recommended for specific inverter topologies [24].

3. LITERATURE REVIEW

The multilevel inverter generates output with a greater number of DC levels which ultimately makes the output closer to our required waveform, the sine wave. It is worth mentioning that higher levels also cause more complexity on the controlling side [25][18][26]. Overview of spectral analysis for multilevel PWM for Voltage Source Inverters (VSI) [2].

The single-phase 5-level CHB multilevel inverter was designed using multicarrier PWM methods with a single reference [27]. Phase shifting switching frequency optimal modulation technique based on five-level cascaded H-bridge MLI and compared its performance with five level SVPWM method and the analyzed results indicated that both the methods are showing similar performance based on the concept of control freedom degrees [28].

For cascaded, hybrid inverters, proposed discontinuous PWM with phase-shifted carriers, resulting in equal harmonic gains to those obtained by the PD-PWM approach; for diode-clamped inverters, this approach works well. [29].

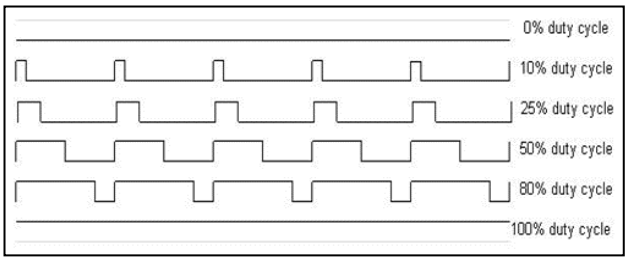

Fig. 2. Comparison of duty cycle generated by an Arduino

Method for calculating switching angles for CHB inverter. The drawbacks of the traditional method are eliminated by this one (such as time-intensive calculations and offline operation) [30]. theoretically investigated and assessed three carriers overlapped PWM approaches for five level three-phase inverters utilizing the double Fourier transform [31].

To forecast the total harmonic distortion and output voltage of a five-level cascaded multilevel inverter, a single carrier modulation based on double integral Fourier. Experimental testing is used to confirm its simulated outcomes [32]. A new adaptive duty cycle modulation algorithm that reduces the losses in the inverter. The main feature of this algorithm is, that output voltage is independent of reference frequency [33].

Using a single reference and a multicarrier sinusoidal PWM control approach, the performance of a three-phase, five-level CHB MLI [34]. For an induction motor drive that is driven by an inverter, the analytical solutions for various multilevel PWM techniques, such as PS-PWM, dipolar modulation, and phase opposite sinusoidal PWM [35].

The literature review suggests that there is a need to have a comprehensive analysis of the performance of multilevel inverters using different SPWM techniques. This paper focuses on carrier-based controlling techniques.

4. 11-LEVEL MULTILEVEL INVERTER TOPOLOGY IMPLEMENTATION

This inverter topology contains a total of eleven output levels in voltage and current waveform. There is a total of five H-Bridges used to design such an inverter as per Eq (2). Each bridge is formed

using four switches so overall 20 switches are used to design the inverter. The Simulink-based circuit for the inverter is shown in Fig. 3.

However, to control the proper conduction sequences of switches, a proper SPWM technique is used. In this paper, we have implemented three already available SPWM techniques; Alternate Phase Opposition Disposition (APOD), Phase Opposition Disposition (POD), and In Phase Disposition (IPD). The diagonal switches are given controlling signals.

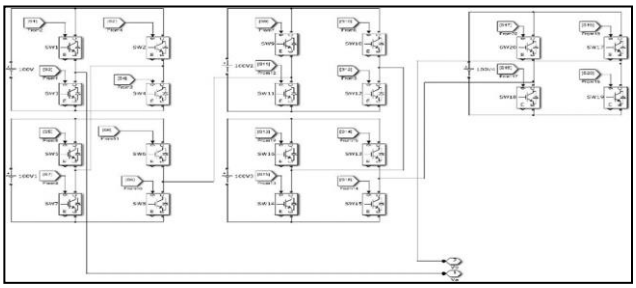

Fig. 3. 11 level Cascaded H-Bridge MLI

4.1 In-Phase Disposition SPWM

In this technique, all carriers are in phase with each other. It is important to make sure that all carriers have the same frequency and amplitude. A single reference signal is compared with each carrier and a pulse train is generated accordingly. If at any time instant, the amplitude of reference is higher than that of the carrier, a high pulse is generated, otherwise low pulse with zero volts is produced. Fig. 4 shows the IPD-SPWM carrier and reference signals for eleven-level inverters. The total number of carriers used is one less required output level; in our case, there are ten triangular carrier signals.

4.2 Alternate Phase Opposition Disposition SPWM

In APOD-SPWM, all controlled signals (carriers) are placed at the angle difference of 180 degrees with that of their adjusting waveforms. The technique can be seen in Fig. 5. However, it is necessary to make the amplitude and frequency of all carriers to be identical and the waveforms placed at odd numbers are in phase with each other [3].

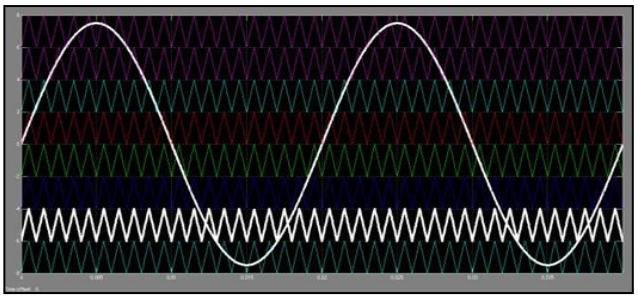

Fig. 4. IPD SPWM Carrier signals

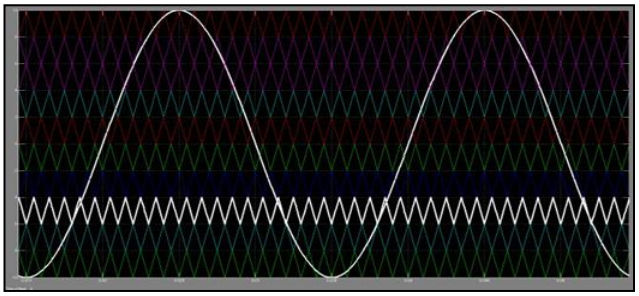

Fig. 5. APOD SPWM Carrier

4.3 signals C. Phase Opposition Disposition SPWM

In POD-SPWM, the controlled signals (carriers) above the zero axis are in phase and those below the zero axis are also in phase. However, the rest of the parameters like frequency and amplitude remain the same for all the carriers. Whereas if any carrier signal above the zero axis is compared with the carrier placed below the zero axis there is a 180-degree phase angle difference [3].

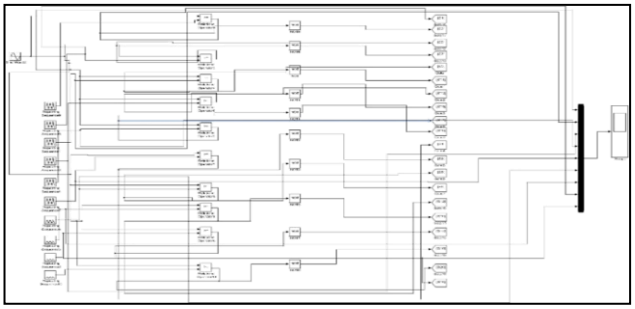

Fig. 6. 11-level SPWMP Signal Generation Circuit

Fig. 6 represents the circuit for the generation of control signals which will make sure the proper conduction sequence of each switch is used in inverter topology. There is a total of 10 triangular carriers which have been used [35].

5. RESULTS AND DISCUSSION

This section focuses on the outcomes of the simulations that were conducted using MATLAB/Simulink. The modulation ratio of 20 is considered throughout the simulation whereas the magnitude of modulation index is varied to understand its relationship with output THD. A passive low pas' filter is also used to filter the voltage harmonics and for the qualitative analysis of each technique. Similarly, each controlling technique is analyzed on different load conditions i-e simple resistive load and RL load with changes in resistance and inductance of loads.

IPD-SPWM

In this part, simulations of the 11-level multilevel inverter are presented when the IPD-SPWM technique is applied.

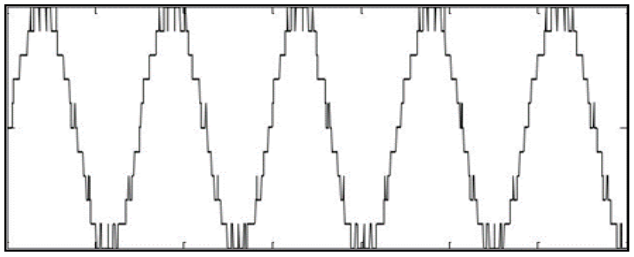

Fig. 7. Output voltage waveform of 11-level MLI using IPD-SPWM

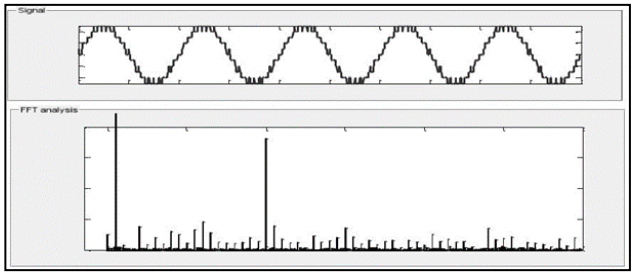

Fig. 8. THD of voltage (without filter) of 11-level CHB

Fig. 7 and Fig. 8 show the output voltage waveform and Total Harmonic Distortion of output voltage respectively, when the IPD-SPWM controlling technique is used. The waveform resembles pure sine wave better than the outputs of less-level topologies [36]. THD of 10.85% in output voltage waveform is achieved. Here, the modulation index is made to be unity and the load is purely resistive. It's important to note, though, that using RL loads has no impact on the output voltage harmonics.

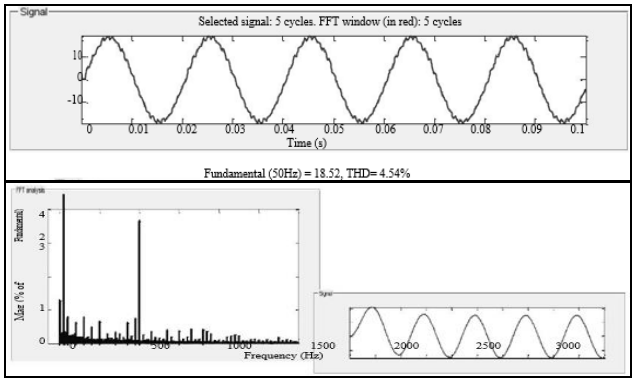

Fig. 9. Output current of 11-level CHB using IPD-SPWM when R=20-ohm, L=10e-3H

Fig. 9 shows the output current waveform harmonics when RL load is used. RL plays a role of minimizing the current harmonics due to the basic principle of an inductor, charging, and discharging. THD of 4.54% in output current waveform satisfies the IEEE standards for maximum harmonic limits. Moreover, the usage of RL load does not cause any effect on voltage distortions.

APOD-SPWM

In this part, the 11-level cascaded H-Bridge Inverter topology is implemented using Alternate Phase Opposition Disposition SPWM technique. Total Harmonic Distortion of current and voltage has been calculated.

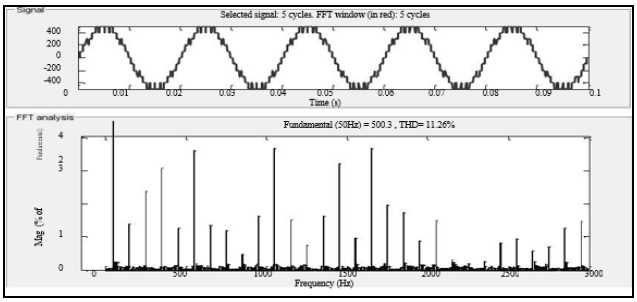

Fig. 10. THD of voltage (without Filter) of 11-level CBH using APOD-SPWM

THD of 11.26% is achieved when 11-level MLI is designed using APOD-SPWM. However filter does not perform positively with this topology due to that fact THD is increased to 13.13% as can be seen in Fig. 10 and Fig. 11 respectively. Though all other parameters including modulation index, modulation ratio and voltage sources are kept samethe .

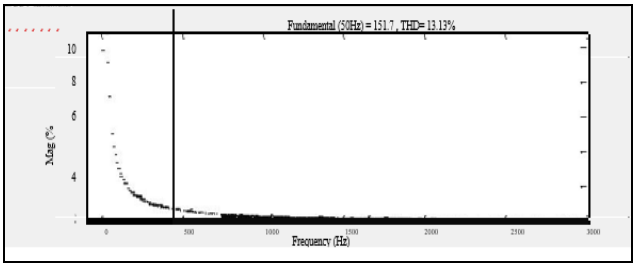

Fig. 11. THD of voltage (with Filter) of 11-level CBH using APOD-SPWM

Fig. 12 describes the THD of 4.42% when RL load is considered. The output current waveform is closer to pure sine waveform. Here R=20ohms and L=10e-3H. The current distortions are comparatively less than what IPD-SPWM generates.

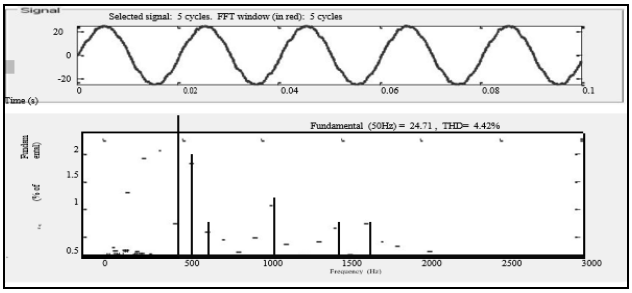

Fig. 12. Current THD (RL Load) for 11-level CBH using APOD-SPWM

POD-SPWM

This part follows the same parameters as used by the previous two parts.

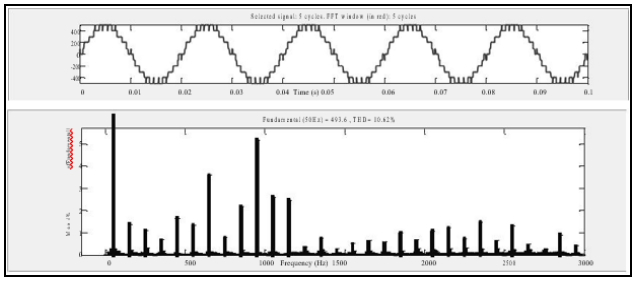

Fig. 13. THD of voltage (without filter) of 11-level CBH using POD-SPWM

10.62% THD is achieved using POD-SPWM for 11-level topology. This is the best result among all other techniques discussed before. The result is quite promising in Fig. 13 However the usage of a low pass filter does not show any positive results rather it adds more distortions in the system as can be seen in Fig. 13.

Fig. 14 shows Current harmonics and they, like voltage harmonics, are also minimum as for as the three controlling strategies are concerned. There is a total of 3.7% THD present in the output current waveform. Here R=20 ohms and L=10e-3H. Mi=1 and Mr=20.

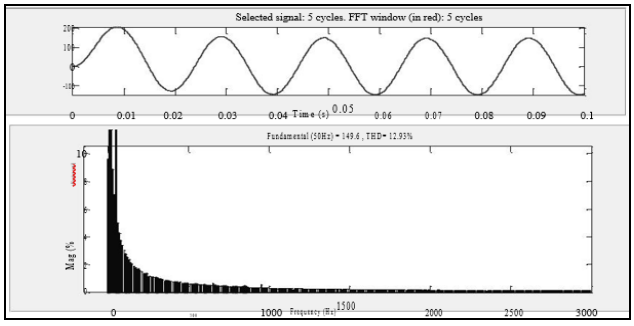

Fig. 14. THD of voltage (with filter) of 11-level CBH using POD-SPWM

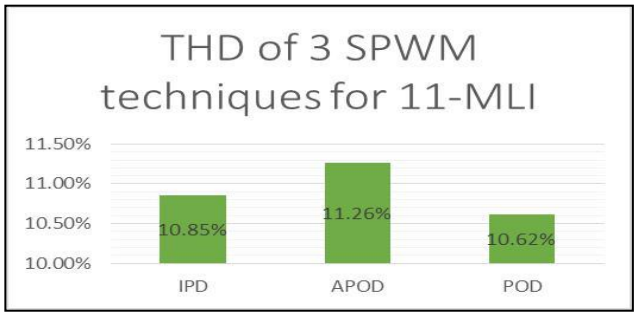

Fig. 15. Comparison of SPWM techniques for 11-level CHB MLI

Fig. 15 shows the comparison of three SPWM techniques IPD, APOD, and POD which have been implemented with the 11-level inverter. From the simulation results, the POD-SPWM technique outperforms in terms of producing minimum output harmonics.

6. CONCLUSION

The simulation findings indicate that a decrease in THD is the result of raising output voltage levels. IPD and APOD generate THD of 10.85% and 11.26% respectively. However, POD has outperformed under consideration with a minimum THD of 10.62% for an 11-level cascaded H-Bridge Inverter. We propose POD-SPWM controlling technique for an 11-level cascaded H-Bridge Inverter based on the simulation results reported in this paper. THD for inductive load is highly decreased for current harmonics, however, there is still a need for the improvement in case of voltage harmonics.

7. DECLARATION OF INTEREST STATEMENT

The authors have no conflict of interest in manuscript writing and data publication.

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