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Discovering Thoughts, Inventing Future

VOLUME 14 ISSUE 6 VERSION 1.0

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Contents of the Volume

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Nano Filler Mixed Enamel Coated Single Phase Capacitor Run Induction Motor

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Abstract- In recent days, there was a tremendous revolution in the application of nano technology in the field of electrical engineering. Nano particles were used as fillers in the polymeric insulating materials to improve the physical, chemical, electrical, mechanical and thermal properties and to avoid tracking in the polymeric insulation. One such application of the nano fillers was practically implemented in the single phase induction motor to improve the performance and the thermal withstanding capacity of the motor. Alumina and silica nano particles were used as fillers for the varnish or enamel used in the single phase induction motor. Enamel was used as coatings for the windings of the motor. The performance and thermal withstanding capacity of the single phase motor was improved by coating the windings of the motor with the enamel filled with Alumina and silica nano particles in the ratio 1:4. From this research, it was observed that the temperature of the nano coated motor was decreased by 9.5% when compared to that of normal motor during daytime. The temperature of the nano coated motor was decreased by 8.6% when compared to that of normal motor during the night time. The efficiency was improved by 19.07% during the daytime by adding nano coating to the single phase induction motor whereas the efficiency was improved by 13.08% during the night time.

Keywords: nano fillers, alumina, silica, single phase induction motor, enamel.

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NANOFILLERMIXEDENAMELCOATEDSINGLEPHASECAPACITORRUNINDUCTIONMOTOR

Nano Filler Mixed Enamel Coated Single Phase Capacitor Run Induction Motor

D. Edison Selvaraj [α], Dr. C. Pughazhendhi Sugumar [σ], J. Ganesan [ρ] & M. Raj Kumar [Ѡ]

Abstract- In recent days, there was a tremendous revolution in the application of nano technology in the field of electrical engineering. Nano particles were used as fillers in the polymeric insulating materials to improve the physical, chemical, electrical, mechanical and thermal properties and to avoid tracking in the polymeric insulation. One such application of the nano fillers was practically implemented in the single phase induction motor to improve the performance and the thermal withstanding capacity of the motor. Alumina and silica nano particles were used as fillers for the varnish or enamel used in the single phase induction motor. Enamel was used as coatings for the windings of the motor. The performance and thermal withstanding capacity of the single phase motor was improved by coating the windings of the motor with the enamel filled with Alumina and silica nano particles in the ratio 1:4. From this research, it was observed that the temperature of the nano coated motor was decreased by 9.5% when compared to that of normal motor during daytime. The temperature of the nano coated motor was decreased by 8.6% when compared to that of normal motor during the night time. The efficiency was improved by 19.07% during the daytime by adding nano coating to the single phase induction motor whereas the efficiency was improved by 13.08% during the night time.

Keywords: nano fillers, alumina, silica, single phase induction motor, enamel.

I. Introduction

1Φ Induction motor has fractional horse power ratings. They were used in fans, washing machines, drillers, record players, refrigerators, and so on. These motors were simple in construction. But have the drawbacks like lack of starting torque, reduced power factor and efficiency. The efficiency and power factor of the single phase induction motor could be improved by adding nano fillers to the enamel used in these motors. Generally, enamel was used for impregnation, coating and adhesion. This project deals with the coating of windings of the motor with enamel filled with various nano fillers. The efficiency, thermal withstanding capacity, power factor and life time of the motors were improved by using several nano fillers such as Al_2O_3, SiO_2, TiO_2, ZrO_2 and ZnO and hence these type of single phase induction motors were simply called as Nano motors. These methods of efficiency improvement could be adopted for the various types of motors used in the industrial and house hold appliances. The majority of Single phase motors were of induction type. Hence, various researches were focussed on these types of motors. The motor power rating was always in the terms of fractional HP. Depending upon the starting methods, they were classified into:

- Split phase Induction motor
- Capacitor start Induction motor
- Capacitors run Induction motor
- Capacitor start Capacitor run Induction motor
- Shaded pole Induction motor

1Φ synchronous motors were used in clocks and turn tables where constant speed was required. 1Φ synchronous motors were of two types: reluctance and Hysteresis type. 1Φ series motor was also called as universal motor. These types of motors can operate either in AC or DC supply. These motors were used in kitchen equipment, portable tools and vacuum cleaners where high starting torque and high speed were required. The construction of 1Φ Induction motor was as similar as 3Φ squirrel cage motor. The rotor was as same as that of a 3Φ Induction motor, but the stator has only a single phase distributed winding. It was consists of stator and rotor. The air gap was uniform between stator and rotor. There was no external electrical connection between stator and rotor but they were magnetically coupled with each other by means of the air gap flux. 1Φ Induction motor was not self starting because it has no self starting torque. This concept was explained by double filed revolving theory and cross field theory. The starting method of 1Φ Induction motor was very simple. An auxiliary winding was provided in addition to the main winding. 1Φ Induction motor were used in compressors, pumps, conveyors, refrigerators, air conditioning machines, washing machines, blowers, turn tables, hair driers and so on. 1Φ Induction motor was having the following demerits: low efficiency, low power factor and very low starting torque. The

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performance of the single phase motors was improved by the application of nano technology in the enamel used for the coatings of these motors.

II. Proposed Work

Ball mill method was an efficient method used for the preparation of nano fillers due to its availability and ease of operation. Ball mill was used for grinding of micro particles into fine nano particles. When compared to other methods of preparation of nano particles, it was economic. Hence, ball mill method was often used for the preparation of nano particles. Ball mill was also available in all the research institutions also. There were two ways of grinding: dry process and wet process. It was widely used for the manufacture of cement, silicate product glass, ceramics and so on. The micro particles of SiO_2 and Al_2O_3 were converted into nano particles by this ball mill method only. SEM was one of the mostly used equipment to augment the particle size of the prepared nano filler. SEM was available in various research centres for augmenting the particle size of the nano powders. In this research, for 100 ml of enamel, 5 gm of nano fillers were added. In the 5 gm of nano composites, 1 gm constitutes Al_2O_3 and 4 gm constitutes SiO_2. These nano fillers were mixed with the enamel by using ultrasonic vibrator. Then this mixed enamel was coated with the windings of the single phase motor. Depending upon the types and size of winding, production rate, several application methods were adopted during the manufacture of electrical machines. In Dip or Flood Impregnation method preheated winding was slowly dipped in the varnish or resin preferably with the slots in vertical direction. After certain time, the winding was removed from the varnish tank excess varnish was allowed to drip and cured. In a slight variation to this simple dip process, the pre dried winding was kept in a varnish tank and varnish pumped to slowly raise the varnish level till the winding was completely submerged. This was called flood impregnation. One of the limitations of this method was that impregnating agent gets coated on unwanted parts of the winding. Pre dried winding was placed in an impregnant chamber which was then evacuated to very low vacuum for Vacuum or Vacuum-Pressure Impregnation (VPI) Method. The impregnating agent was fed in till complete submersion of winding. For further penetration in compact or fine size wire wound units, dry compressed air or Nitrogen pressure was applied, after breaking vacuum. VPI method was generally employed for electrical machines and coils requiring high quality impregnation. In Trickle Impregnation method, a thin jet of impregnating resin was poured on to preheated & rotating winding, sometimes kept inclined to the horizontal axis. The impregnating resin penetrates through the winding and gets polymerized in a short time. The method offers several advantages such as short processing time, no long post curing, no drain loss, high retention and consistent quality of impregnation. Finishing varnishes were used to give an enveloping coat over the exposed impregnated winding for additional protection against moisture, chemical fumes and dust. Finishing varnish or resin was generally applied by brushing and spraying. Depending upon the type used, the winding was cured at ambient or elevated temperature in an oven. The specification of the single phase motor used for this study was shown in the table 1. Various tests were conducted on the single phase motor to find the efficiency and thermal withstanding capacity of the motor. Load test was conducted to find the performance of the single phase motor whereas Heat run test was conducted to find the thermal withstanding capacity of it. The proposed work was shown in the figure 1.

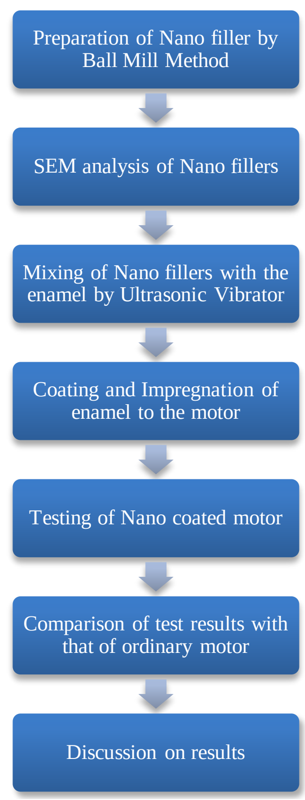

Figure 1 : Proposed work set up

Table 1 : Specification of the Motor

Motor Type	Capacitor run Induction Motor
Phase	1Φ
Capacity	¼ HP
Rated voltage of motor	230 V
Rated current of motor	2.5 A
Frequency	50 Hz
No of poles	4
Synchronous Speed of the Motor	1500rpm
Capacitor value	10 μF
Insulation	Class B

No of slots per pole pitch	4
Pole/pitch	4/6
No of slots	24
No of turns on running winding	70,140
No of turns on starting winding	90,185
Copper for running winding	26 SWG
Copper for starting winding	27 SWG
Type of winding	Single layered lap winding
Type of slots	Semi closed even slots

III. Experimental

a) Heat Run Test

The thermal withstanding capacity of the motor during day time and night time was observed by conducting heat run test. The initial temperature of the motor during day time and night time was noted. Then the time was increased gradually by 5 minutes and the temperature was noted during day time and night time. The table 2 shows the thermal withstanding capacity of both normal single phase motor and nano coated single phase motor during day time and night time. The maximum temperature rise of the normal motor was 63º C during day time whereas that of the nano coated motor was 57º C. The maximum temperature rise of the normal motor was 58º C during night time whereas that of the nano coated motor was 53º C. The temperature of the nano coated motor was decreased by 6º C when compared to that of normal motor during day time. The temperature of the nano coated motor was decreased by 5º C when compared to that of normal motor during night time. The thermal withstanding capacity of the motor was increased by adding nano fillers to the enamel used for coating the windings of the motor. The temperature of the nano coated motor was decreased by 9.5% when compared to that of normal motor during daytime. The temperature of the nano coated motor was decreased by 8.6% when compared to that of normal motor during night time. Figure 2 shows the Comparison of thermal withstanding capacity of various motors during day time and night time.

Table 2 : Comparison of thermal withstanding capacity of various motors

Time in min.	Normal Motor Temperature in ºC (Day Time)	Nano coated Motor Temperature in ºC (Day Time)	Normal Motor Temperature in ºC (Night Time)	Nano coated Motor Temperature in ºC (Night Time)
0	46.3	36	38	30
5	49.1	38	39	34.5
10	51.5	39	41	39
15	52.7	41	45.5	44
20	54	45.5	51	46
25	55.5	51	54	49
30	57.2	54	56	51
35	59	56	57	52
40	63	57	58	53

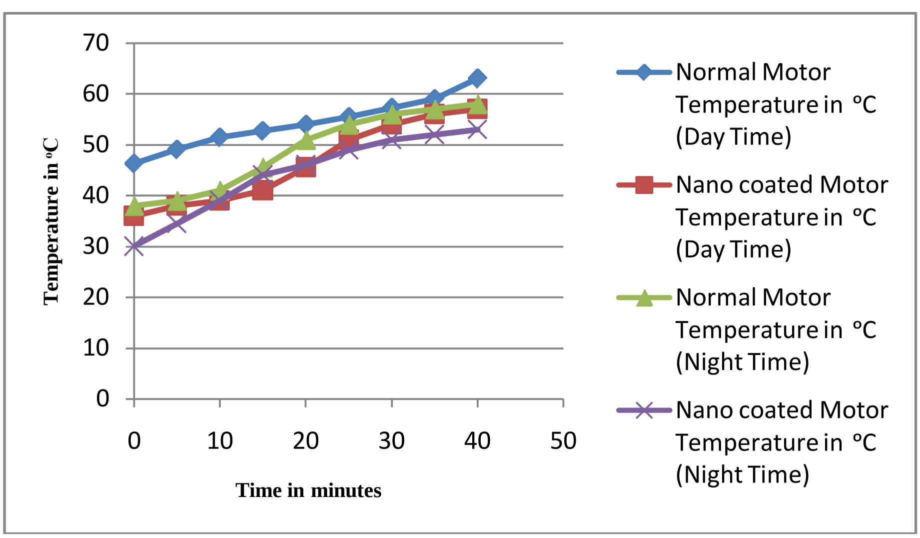

Figure 2 : Comparison of thermal withstanding capacity of various motors during day time and night time

b) Load Test

The performance of the single phase induction motor was found by using direct loading. The connections were given as per the circuit diagram shown in the figure 3. The supply was switched on. One set of readings were taken at no load. The load was varied in suitable steps and all the meter readings were noted up to 120% of full load. The load test was conducted during day time and night time and the readings were shown in the table 3 to 6 for both the normal motor and nano coated motor. The different performance curves of the single phase induction motor before and after nano coating were shown in the figure 4 to 15. The maximum efficiency obtained from the single phase induction motor before nano coating was 59.05% during daytime whereas that of the single phase induction motor after nano coating was 78.12%. Similarly the maximum efficiency obtained from the single phase induction motor before nano coating was 57.75% during night time whereas that of the single phase induction motor after nano coating was 70.83%. The efficiency was improved by 19.07% during the daytime by adding nano coating to the single phase induction motor whereas the efficiency was improved by 13.08% during the night time.

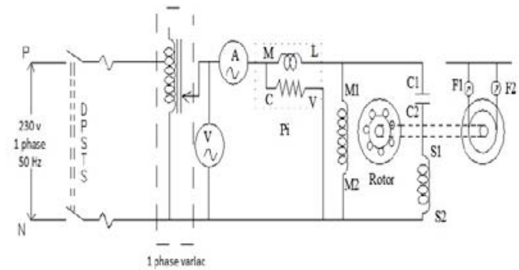

Figure 3 : Circuit diagram for Load test on Single phase Induction motor

The range of meters used for the load test was given as follows:

Range of Voltmeter: (0 – 300 V), moving iron

Range of Ammeter: (0 – 5 A), moving iron

Range of Wattmeter: 300 V, 5 A, UPF

Fuse rating: 5 A

Table 3 : Load Test on Normal Motor at Daytime

S. No	Voltage (volts)	Current (Amps)	Input Power (Watts)	Spring Balance		Speed (rpm)	Torque (N-m)	Output Power (Watts)	Power Factor	Slip (%)	Efficiency (%)
				S_1	S_2						
1	230	1.25	120	0	0	1484	0	0	0.417	1.06	0
2	230	1.4	220	1	2	1430	0.56	83.86	0.683	4.67	38.12
3	228	1.5	240	1	2.5	1410	0.84	124.03	0.701	6	51.68
4	228	1.7	310	1.5	3.5	1348	1.12	158.10	0.799	10.1	51
5	226	1.85	340	1.5	4	1328	1.40	194.69	0.813	11.4	57.26
6	226	2	390	1.5	4.5	1309	1.68	230.29	0.863	12.7	59.05

Table 4 : Load Test on Normal Motor at Night time

S. No	Voltage (volts)	Current (Amps)	Input Power (Watts)	Spring Balance		Speed (rpm)	Torque (N-m)	Output Power (Watts)	Power Factor	Slip (%)	Efficiency (%)
				S_1	S_2						
1	214	1.05	100	0	0	1480	0	0	0.455	1.33	0
2	216	1.2	180	1	1.5	1442	0.28	42.3	0.694	3.86	23.5
3	218	1.4	220	1.5	2.5	1412	0.56	82.8	0.721	5.86	37.64
4	218	1.6	280	1.5	3	1360	0.84	119.63	0.803	9.33	42.73
5	218	1.8	350	1.5	4	1342	1.4	196.75	0.892	10.53	56.21
6	218	2.0	390	1.5	4.5	1280	1.68	225.2	0.894	14.66	57.74
7	218	2.1	400	2	5	1228	1.68	216.04	0.873	18.13	54.01
8	218	2.2	420	2.5	5.5	1196	1.68	210.41	0.876	20.26	50

Table 5 : Load Test on Nano coated Motor at Daytime

S. No	Voltage (volts)	Current (Amps)	Input Power (Watts)	Spring Balance		Speed (rpm)	Torque (N-m)	Output Power (Watts)	Power Factor	Slip (%)	Efficiency (%)
				S_1	S_2						
1	218	1.05	100	0	0	1488	0	0	0.436	0.8	0
2	218	1.2	190	0.5	1.5	1436	0.56	84.21	0.726	4.27	44.32
3	218	1.45	240	0.5	2.5	1392	1.12	163.26	0.786	7.2	68.03
4	216	1.6	270	1	3.5	1360	1.4	199.39	0.781	9.3	73.85

5	215	1.8	330	1	4	1296	1.68	228	0.852	13.6	69.1
6	215	1.9	360	1.5	5	1258	1.96	258.21	0.881	16.1	71.73
7	215	1.95	370	1.5	5.5	1232	2.24	289	0.882	17.87	78.12

Table 6 : Load Test on Nano coated Motor at Night time

S. No	Voltage (volts)	Current (Amps)	Input Power (Watts)	Spring Balance		Speed (rpm)	Torque (N-m)	Output Power (Watts)	Power Factor	Slip (%)	Efficiency (%)
				S_1	S_2						
1	218	1	110	0	0	1482	0	0	0.504	0.06	0
2	218	1.15	170	0.5	1.5	1436	0.559	84.06	0.678	4.2	49.45
3	218	1.3	210	0.5	2	1420	0.838	124.61	0.741	5.33	59.34
4	218	1.5	240	1	2.5	1396	0.838	122.51	0.733	6.93	51.04
5	218	1.75	320	1	3.5	1352	1.397	197.79	0.838	9.86	61.81
6	218	1.9	360	1.5	4.5	1310	1.677	230.1	0.869	12.6	63.92
7	218	2	390	1.5	5	1282	1.96	263.13	0.894	14.5	67.46
8	221	2.25	410	1.5	5.5	1238	2.24	290.4	0.824	17.4	70.83

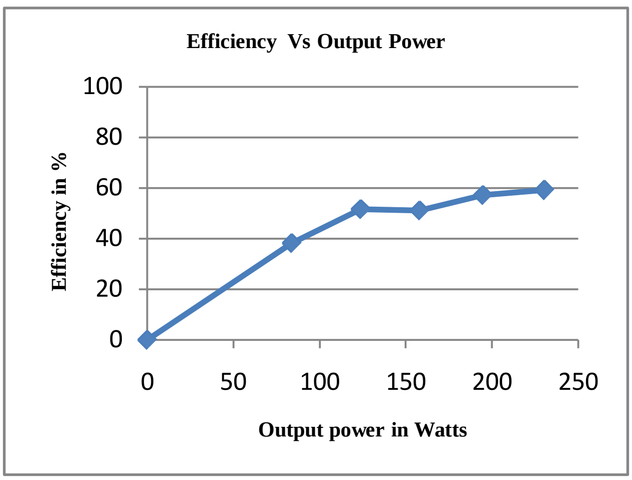

Figure 4 : Efficiency Vs Output Power for Normal Motor at Daytime

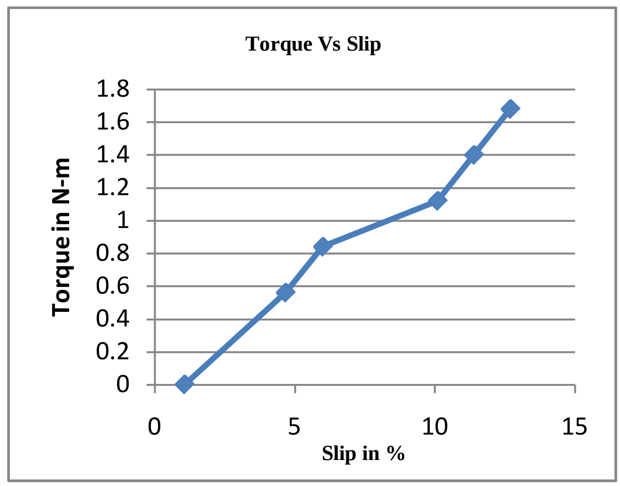

Figure 6 : Torque Vs Slip for Normal Motor at Daytime

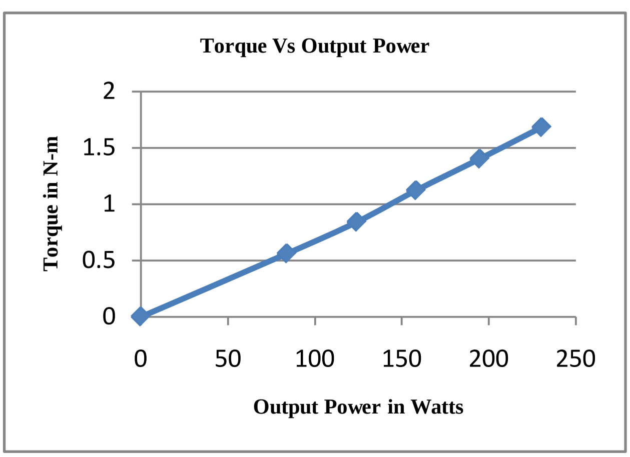

Figure 5 : Torque Vs Output Power for Normal Motor at Daytime

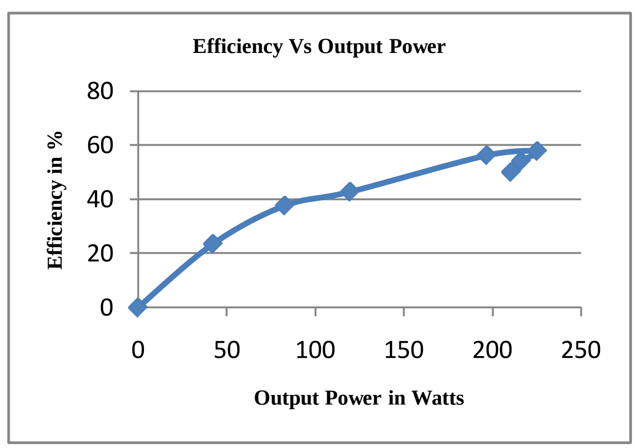

Figure 7 : Efficiency Vs Output Power for Normal Motor at Night time

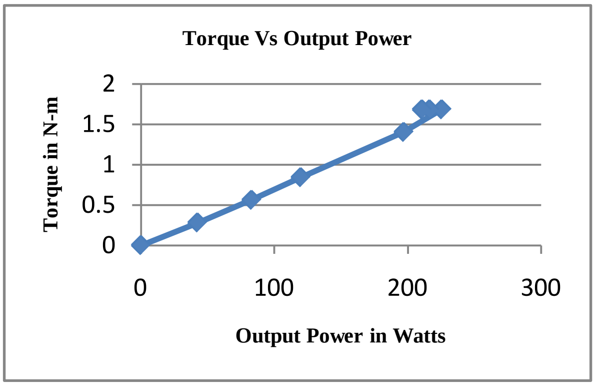

Figure 8 : Torque Vs Output Power for Normal Motor at Night time

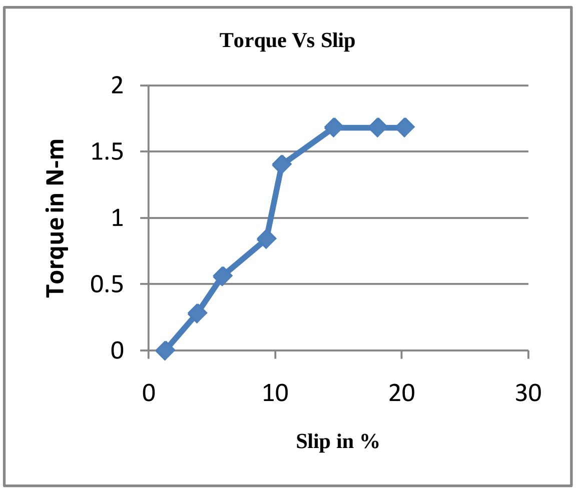

Figure 9 : Torque Vs Slip for Normal Motor at Night time

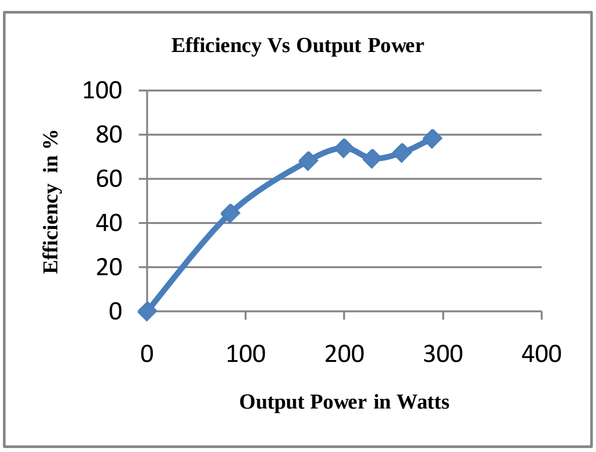

Figure 10 : Efficiency Vs Output Power for Nano coated Motor at Daytime

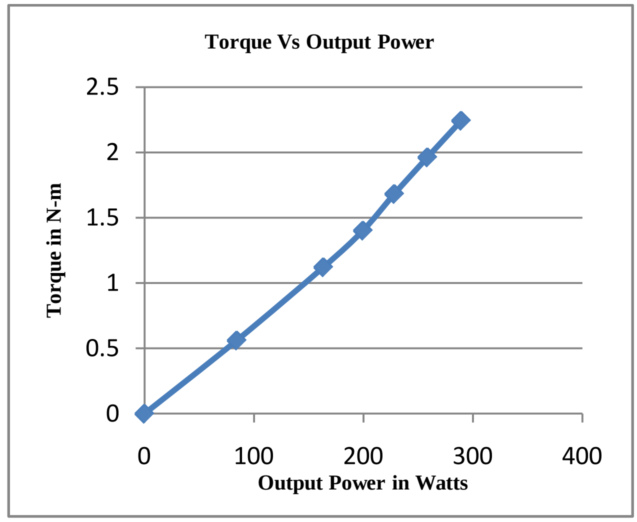

Figure 11 : Torque Vs Output Power for Nano coated Motor at Daytime

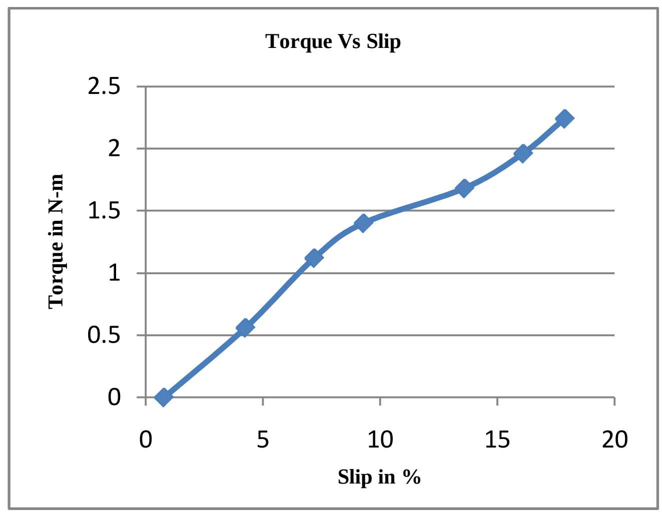

Figure 12 : Torque Vs Slip for Nano coated Motor at Daytime

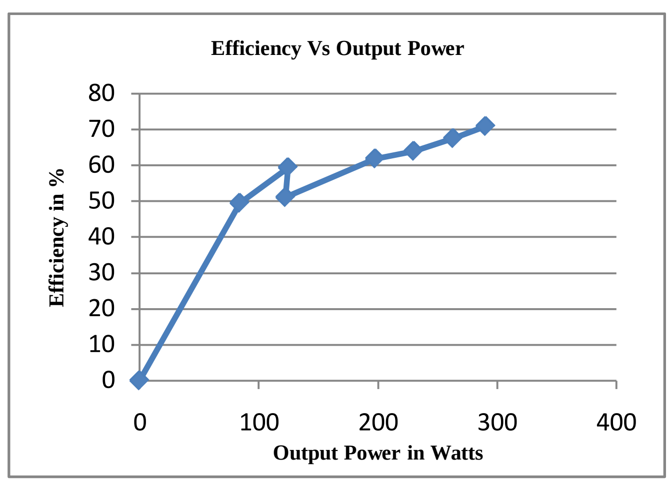

Figure 13 : Efficiency Vs Output Power for Nano coated Motor at Night time

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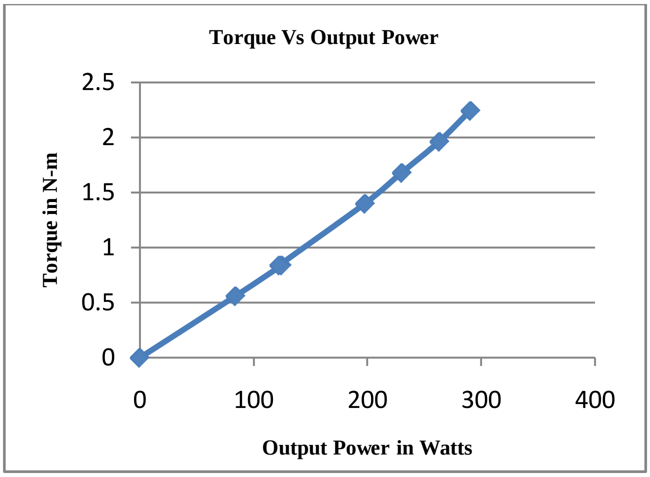

Figure 14 : Torque Vs Output Power for Nano coated Motor at Night time

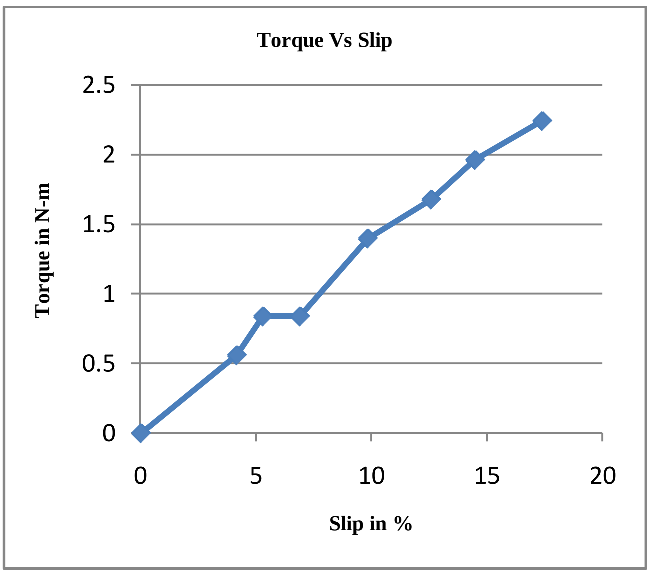

Figure 15 : Torque Vs Slip for Nano coated Motor at Night time

IV. Conclusions

The following observations were made as clear from this research:

- The temperature of the nano coated motor was decreased by 9.5% when compared to that of normal motor during daytime. The temperature of the nano coated motor was decreased by 8.6% when compared to that of normal motor during night time.
- The efficiency was improved by 19.07% during the daytime by adding nano coating to the single phase induction motor whereas the efficiency was improved by 13.08% during the night time.

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Speech Enhancement using Boll's Spectral Subtraction Method based on Gaussian Window

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Abstract- This paper investigates the effect of Gaussian window frequency response Side lobe Attenuation on the improvement of Speech quality in terms of six objective quality measures. In Speech Enhancement process, signal corrupted by noise is segmented into frames and each segment is Windowed using Gaussian window with variation in the side lobe attenuation parameter "**α**". The Windowed Speech segments are applied to the Boll's Spectral Subtraction Speech Enhancement algorithm and the Enhanced Speech signal is reconstructed in its time domain. The focus is to investigate the effect of Gaussian window frequency response side lobe level on the Boll's Spectral Subtraction Speech enhancement. For various side lobe attenuations of the Gaussian window frequency response, speech quality objective measures have been computed. From this study, it is observed that the Side lobe Attenuation parameter "**α**" plays an important role on the Speech enhancement process in terms of six objective quality measures. The results are compared with the measures of Hamming window and an optimum side lobe attenuation parameter value for the Gaussian window is proposed for better speech quality.

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I. Introduction

In Speech Processing, Speech enhancement is one of the most important fields and finds many applications such as mobile phones, teleconferencing systems, speech recognition and hearing aids. The processed speech signals are supposed to be more comfort for listening and also should give better performance in tasks like automatic speech and speaker recognition [1]. Several algorithms are proposed in the literature for speech enhancement such as spectral subtraction methods, MMSE methods, Weiner algorithm etc. [2]. This paper attempts the Boll's Spectral Subtraction method of Speech Enhancement [3]. In this Method, the noisy speech signal is partitioned into frames. Each frame is multiplied by a window function prior to the spectral analysis and applied to the speech enhancement algorithm. This work investigates the effect of windowing the speech signal in the process of Speech Enhancement in terms of six Objective Speech Quality measures using Boll's Spectral Subtraction Method for Speech Enhancement process.

The purpose of windowing is to reduce the effect of discontinuity introduced by the framing process. Commonly used windows include Hamming and Hanning [4]. Although these windows have a reduced side lobe levels they have also reduced frequency resolution. Hence several factors enter into the choice of Window selection to frame the Speech for Enhancement. In this paper an attempt has been made to explore the possibility of improving the quality of speech signal by employing Gaussian window with different "**α**"values. To study the performance of any algorithm, combinations of subjective and objective measures have to be carried on. Currently, the accurate method for evaluating speech quality is through subjective listening tests. But it is costly and time consuming. Hence, six Objective measures are chosen to evaluate the performance of the Gaussian window in the enhancement system. P. Loizou has presented a correlation analysis of Objective Quality measures for evaluating speech enhancement algorithms [5]. In this paper six measures namely SNR, Segmental SNR (Seg-SNR), Log Likelihood Ratio(LLR), Weighted spectral slope distance(WSS), Frequency weighted segmental SNR (fwseg-SNR) and Cepstral Distance (Cep) are selected for performance evaluation test, considering the fact that Fwseg-SNR, LLR, Cep and WSS have high correlation with overall speech quality. The correlation coefficients for these measures with speech quality are 0.84, 0.85, 0.79 and 0.64 respectively [5]. These objective measures also have good correlation with subjective scores. Although the correlation coefficient of SegSNR is 0.36, it is chosen as a time domain measure where as the above measures are of frequency domain. This paper explains the effect of the shape parameter of the Gaussian window on the noisy speech for Enhancement in terms of the six Objective measures using Speech Enhancement algorithm. The rest of the paper is organized as follows: Section-2 briefly explains the various windows for noisy Speech Enhancement. In Section-3, the Six Objective measures used in this study are presented. In Section-4 Boll's Spectral Subtraction method for noisy speech enhancement is explained. Implementation of the scheme is presented in Section-5, Section-6 explains the results and discussions, Section- 7 presents the Simulation Results and finally Section-8 describes the conclusions.

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II. Data Weighting Windows

a) Windowing

Windows are time-domain weighting functions that are used to reduce Gibbs' oscillations resulting from the truncation of a Fourier series [6-7]. Their roots date back over one-hundred years to Fejer's averaging technique for a truncated Fourier series and they are employed in a variety of traditional signal processing applications including power spectral estimation, beam forming, and digitalfilter design. The effect of a time window can be described in the frequency domain as a convolution of the frequency response of the window with the frequency response of the signal. The convolution smears frequency features, with the amount of smearing depending on the width of the main lobe of the window frequency response. For signal frequencies, observed through the rectangular window, which do not correspond exactly to one of the sampling frequencies, the pattern is shifted such that non-zero values are projected onto all sampling frequencies. This phenomenon of spreading signal power from the nominal frequency across the entire width of the observed spectrum is known as spectral leakage. In addition, spectral leakage from distant frequency components will occur if the side lobe level of the window response is large [8-18]. Ideally, the window spectrum should have a narrow main-lobe and small side-lobes. However, there is an inherent trade-off between the width of the main-lobe and the side-lobe attenuation. A wide main-lobe will average adjacent frequency components and large side lobes will introduce contamination (or spectral leakage) from other frequency regions. For rectangular window, the main lobe is narrower than that of the Hamming window, while its side-lobes are higher. Some of the commonly used windows in speech processing are symmetric (e.g., Hamming and Hanning windows) or asymmetric (such as the hybrid Hamming-Cosine window). The goal of asymmetric windows is to reduce the algorithmic delay in speech codes.

b) Gaussian Window

In contrast to the other fixed windows, the Gaussian Window [8] has two parameters: the length of the sequence N and a shape parameter "α". In short-time spectral amplitude (STSA), the length of the window is fixed and is equal to the speech signal frame length and hence the side lobe attenuation parameter "α" can be varied. As the parameter increases the side lobe level of the frequency response decreases. In this paper, the speech enhancement in terms of objective measures as a function of side lobe attenuation parameter "α" has been investigated.

The Gaussian Window can be obtained using (1). Figures 2.1 and 2.2 indicate the time and frequency description of a Gaussian Window with α=2.5 and α=3.5 respectively.

$$w(n) = e^{-\frac{1}{2}\left(\alpha\frac{n}{N/2}\right)^2} \qquad 0 \le |n| \le N/2 \qquad (1.1)$$

Where, "α" is inversely proportional to the standard deviation of a Gaussian random variable. The exact correspondence with the standard deviation, "σ", of a Gaussian probability density function is

$$\sigma = \frac{N}{2\alpha} \qquad (2.2)$$

The width of the window is inversely related to the value of "α", a larger values of "α" produces a narrower window.

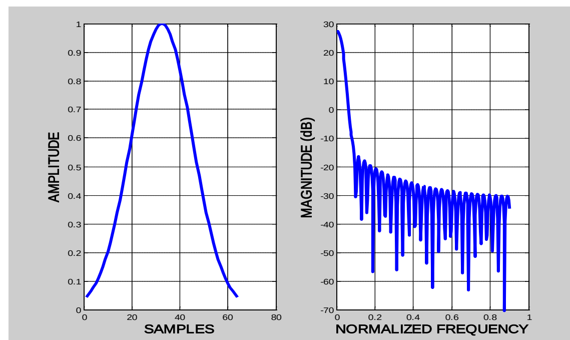

Figure 2.1 : The time and frequency description of a Gaussian Window with "α=2.5"

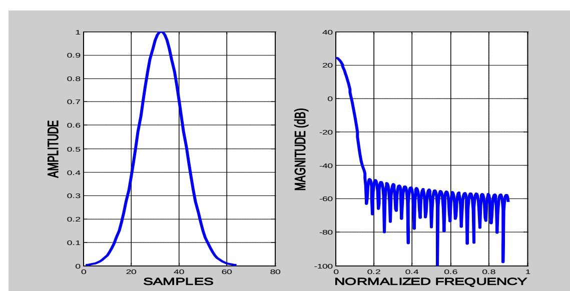

Figure 2.2 : The time and frequency description of a Gaussian Window with "α=3.5"

III. Objective Measures

a) Signal-to–Noise Ratio

The Signal-to-Noise Ratio (SNR) is the ratio of signal energy to noise energy and is expressed in decibels dB given by [2,4-5] as

$$SNR_{dB} = 10\log_{10}\left[\frac{\sum_n s^2(n)}{\sum_n [s(n)-\hat{s}(n)]^2}\right] \qquad (3.1)$$

Where s(n) is the undistorted or clean signal and $\hat{s}$ (n) is the degraded or processed/enhanced speech signal , N is the frame length.

b) The Seg-SNR

The Seg-SNR is the frame-based SNR and is estimated as It is defined [2,4-5] as

$$SegSNR_{dB} = \frac{1}{M}\sum_{m=0}^{M-1} 10\log_{10}\left[\frac{\sum_{n=0}^{N-1}|s(n+mN)|^2}{\sum_{n=0}^{N-1}|s(n+mN)-\hat{s}(n+mN)|^2}\right] \qquad (3.2)$$

Where s(n) is the undistorted or clean signal and $\hat{s}$(n) is the degraded or processed / enhanced speech signal , N is the frame length. M represents the number of frames. The Seg-SNR poses a problem if there are intervals of silence in the speech utterance. In segments in which the original speech is nearly zero, any amount of noise can give rise to a large negative SNR for that segment, which could appreciably bias the overall measure of Seg-SNR. This problem is resolved by including the SNR of the frames only if the frame energy is above a specified threshold. Generally, the frames with segmental SNR between –10 dB to 35 dB are only considered in the average.

c) Weighted Spectral Slope Distance

WSS distance measure computes the weighted difference between the spectral slopes in each frequency band. The spectral slope is obtained as the difference between adjacent spectral magnitudes in decibels. The WSS measure is defined and evaluated [19] as

$$WSS = \frac{1}{M}\sum_{m=0}^{M-1}\left[\frac{\sum_{j=1}^{k} W(j,m)[s_c(j,m)-s_p(j,m)]^2}{\sum_{j=1}^{k} W(j,m)}\right] \quad (3.3)$$

Where W (j, m) are the weights computed. S_c (j, m) and S_p(j, m) are the spectral slopes for j^{th} frequency Band at m^{th} frame of clean and processed speech signals respectively.

d) Log Likelihood Ratio

The LLR measure is defined [20] as

$$\text{LLR}=\log_{10}\left[\frac{a_p R_s a_p^T}{a_s R_s a_s^T}\right] \quad (3.4)$$

Where a_p and a_s are the LP coefficient vectors for the clean and degraded or enhanced speech segments, respectively. Rs denote the autocorrelation matrix of the clean speech segment.

e) Cepstrum Distance

The Cepstrum distance [6] provides an estimate of the log spectral distance between two spectra. It is defined as

$$WSS = \frac{1}{M}\sum_{m=0}^{M-1}\left[\frac{\sum_{j=1}^{k} W(j,m)[s_c(j,m)-s_p(j,m)]^2}{\sum_{j=1}^{k} W(j,m)}\right] \quad (3.5)$$

Where C_s(n) and C_p(n) represent the cepstrum of clean and the degraded or enhanced speech respectively.

$$C_s(k,m)=\text{Re}[\text{IDFT}\{\log|DFT(s(k,m)|\}] \quad (3.6)$$

The cepstrum coefficients can also be obtained recursively from the LPC coefficients using the following expression [2, 5]

$$c(m) = a_m + \sum_{k=1}^{m-1}\frac{k}{m}\,c(k)a_{m-k} \quad \text{for } 1\le m\le p \quad (3.7)$$

f) Frequency Weighted Segmental SNR

It is computed [5, 21] using the following equation

$$fwSNRseg = \frac{10}{M}\sum_{m=0}^{M-1}\left\{\frac{\sum_{j=1}^{k} W(j,m)\log_{10}\frac{s(j,m)^2}{[s(j,m)-\hat{s}(j,m)]^2}}{\sum_{j=1}^{k} W(j,m)}\right\} \quad (3.8)$$

where W (j, m) is the noise-dependent weight applied on the jth frequency band, K is the number of bands, M is the total number of frames in the signal, s(j, m) is the weighted (by a Gaussian-shaped window) clean signal spectrum in the jth frequency band at the mth frame, and $\hat{s}$(j, m) in the weighted enhanced signal spectrum in the same band.

IV. Boll's Spectral Subtraction Method

The noise corrupted speech is processed by the Spectral Subtraction method to get processed or enhanced speech. Spectral Subtraction [3, 22, 24-25] is a popular frequency domain method to reduce the effect of additive uncorrelated noise in a signal. The noise spectrum is estimated, and updated, from the periods when the signal is absent and only the noise is present. For restoration of the time-domain signal, an estimate of the instantaneous magnitude spectrum is combined with the phase of the noisy signal, and then transformed via an Inverse Discrete Fourier Transform (IDFT) to the time domain.

If y(n) is the discrete noise corrupted input signal which is composed of the clean speech signal s(n) and v(n) the uncorrelated additive noise signal, then the noisy signal can be represented as:

$$y(n) = s(n) + v(n) \quad (4.1)$$

Since the speech is not a stationary signal, the processing is carried on short-time basis (frame-by-frame).

$$y(n, k) = s(n, k) + v(n, k) \quad (4.2)$$

Where n is the time index and k is the frame index, y(n, k) is the k th frame. In the frequency domain, with their respective Fourier transforms, the power spectrum of the noisy signal can be represented as:

$$P_{yy}(w,k)=P_{ss}(w,k)+P_{vv}(w,k) \quad (4.3)$$

$$|Y(w,k)|^2=|S(w,k)|^2+|V(w,k)|^2 \quad (4.4)$$

Here Y(w, k) is the DFT of y(n, k) given by

$$Y(w,k) = \sum_{n=0}^{N-1} y(n,k)e^{-j\frac{2\pi wn}{N}} = |Y(w,k)|\, e^{j\varphi(w)} \quad (4.5)$$

Where φ(w) is the phase of the corrupted noisy signal, and N is the number of samples in the framed speech signal.

Thus from Eq.4.4 the estimation of clean speech signal can be given as

$$|\hat{S}(w,k)|^2=|Y(w,k)|^2-|\hat{V}(w,k)|^2 \quad (4.6)$$

Once the estimate of the clean speech is obtained in the spectral domain, the enhanced speech signal is obtained according to:

$$\hat{s}(n,k) = \mathrm{IDFT}\{|\hat{S}(w,k)|e^{j\varphi(w)}\} \quad (4.7)$$

Here, the phase information from the corrupted signal is used to reconstruct the time domain signal by taking the IDFT.

One may generalize the technique of spectral subtraction by replacing the magnitude squared of the DFT by some power of the magnitude. The exponent, '2', in Equation.4.6 can be replaced by 'a' as given below:

$$|\hat{S}(w,k)|^a = |Y(w,k)|^a - |\hat{V}(w,k)|^a \quad (4.8)$$

To estimate the noise, a method of exponential averaging proposed in [23] is used to estimate the noise. The frame-by-frame update scheme using the exponential averaging method is given below:

$$|\hat{V}(w,k)|^a = \begin{cases} \mu|\hat{V}(w,k-1)|^a + (1-\mu)|\hat{Y}(w,k)|^a & \text{for } \textit{Noise only} \\ |\hat{V}(w,k)|^a & \text{Speech and Noise} \end{cases} \quad (4.9)$$

In this paper, all the measures were evaluated with a = 1 by restricting the study for magnitude spectrum only.

Where $0 \leq \mu \leq 1$ is exponential averaging constant. In this work "μ" is selected as 0.9. The block diagram for the overall spectral subtraction algorithm is shown in Figure5.1 below.

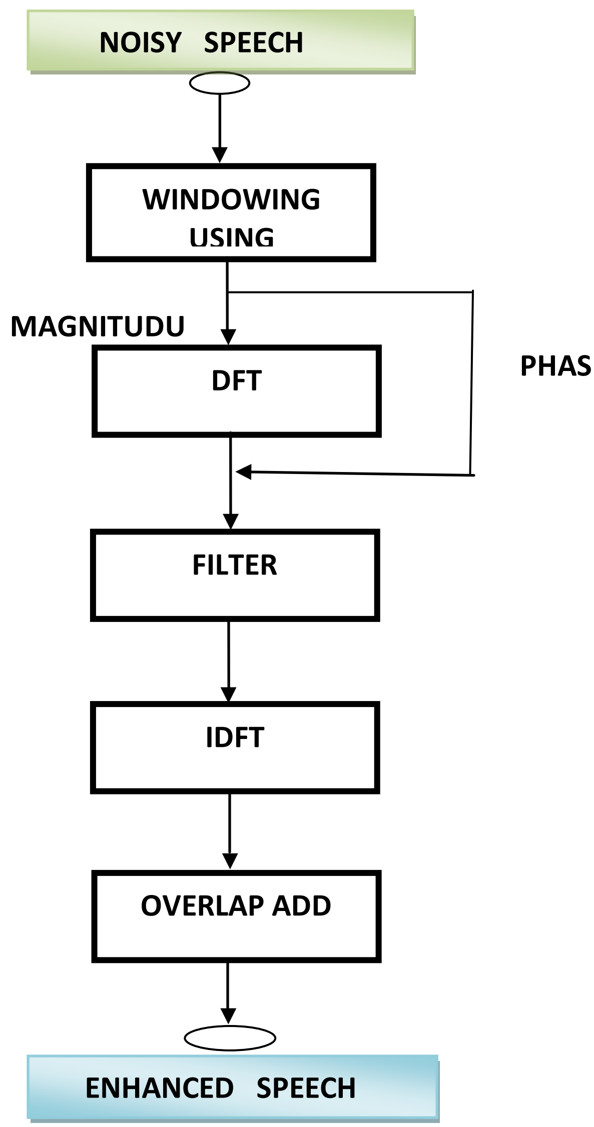

Figure 4.1 : Block diagram for Spectral Subtraction Algorithm

V. Implementations

Phonetically balanced clean speech signals and noise corrupted signals at different SNR levels have been taken from a speech corpus called "NOIZEUS". Noise corrupted speech signal is segmented into frames containing 256 samples of 32ms length (at 8 KHz Sampling rate). 256- point Discrete Fourier Transform (DFT) of each segment is obtained after applying the Gaussian window with variable shape parameter **"α".**

Spectral Subtraction Algorithm is applied to the spectral components of each segment using Eq.4.1-Eq.4.9. The signal is reconstructed in its time domain with the help of IDFT and overlap add method (with 50% overlap between frames). The signal thus obtained is the enhanced signal. The performance of the enhanced signal is analyzed by using six objective measures for speech enhancement. The measures are WSS, LLR, fwseg-SNR, Cep, Seg-SNR, and SNR defined in Eq.3.1-Eq.3.8. All the measures are computed by segmenting the sentences using 32-ms duration Hamming windows with 75% overlap between adjacent frames. A tenth order LPC analysis was used in the computation of LPC-based objective measure LLR. The performance of Gaussian windowed signal is studied under two real world noise conditions namely "Car noise" and "Airport noise" at 0dB, 5dB, 10dB and 15dB SNR levels and presented in Table.1 (a)-1(h) and Table.2 (a)-2(h)

VI. Results and Discussions

The Objective measure scores are shown in Fig. 2(a) - 2(b) as a function of the shape parameter **"α"** of the Gaussian window used as analysis window. The following observations can be made based on these results. For the narrow main lobe width of the analysis Window's frequency response, the Objective measure scores are good and as expected. The measures WSS, LLR and CEPSTRAL DISTANCE increase with the increase of **"α".** This result indicates that, the main lobe width of the analysis Window increases and contributes the unwanted noise for the noise corrupt signal which results degradation in the Speech Enhancement process.

It is important to note that Fig. 2(a)-2(h) shows steep variation in Objective measures is observed when the shape parameter **"α"** is in between 0.3 and 0.8 for Car Noise and between 1.5 and 3.5 for Airport noise, the shape of the analysis window's frequency response plays significant role on the speech quality measures in terms of the above objective measures. It is also observed that, further increase beyond 1.0 for Car noise and beyond 3.5 for Airport noise in the shape parameter **"α"** there is no significant improvement in the objective intelligibility scores as a function of analysis window shape variable. This can be attributed by the fact that the main lobe width and side lobe levels of the window's frequency response are compliment to each other. Narrower level main lobe width will tend to increase the side lobe levels and vice versa. Hence the contribution of undesired spectral components due to the main lobe width will be compensated due to the reduced side lobe levels. Hence the overall improvement in the Objective measures is not observed as in the case of variation of the shape parameter values beyond the above specified values. Based on objective intelligibility scores, it can be seen that the optimum window shape parameter for speech analysis is between 0.3 and 0.8 for Car noise and between 1.5 and 3.5 for Airport noise. For speech applications based solely on the short-time magnitude spectrum, the Gaussian window with the above shape parameter is expected to be the right choice. This study proposes that the optimum shape parameter for the Gaussian window is α=0.5 for Car Noise and 2.8 for Airport Noise.

Comparative analysis of Gaussian window with the Hamming window using six objective measures of speech quality is made for the case of speech signal contaminated with Car noise and Airport noise at various SNRs of 0dB, 5dB, 10dB and 15dB along with clean speech signals. The results are presented in Table.1 (a)-1(h) and Table.2 (a)-2(h). Considering the fact that, higher SNR, Seg-SNR and fwseg-SNR values give better quality where as WSS, Cep and LLR measures, lower values indicate a better quality. From the Table.1 (a)-1(h) and Table.2 (a)-2(h), shown, it can be noticed that majority of the objective measures are improved for Gaussian Window with shape parameter **"α"** when compared with Hamming windowed measure. From WSS measure it is observed that, a significant improvement is achieved with the proposed window scheme. Observing the results presented in the Tables, the proposed window method shown is able to remove the residual noise in better manner compared to the Hamming window method and observing all the results, one can have a judicious choice for **"α=0.5"** Car noise and **"α=2.8"** for Airport noise as optimum values and can be used for Speech Enhancement process for better results using Spectral Subtraction method.

Further from the Fig (2a) for the case of Car noise it is observed that under low noise conditions (0dB), comparing with Hamming window the Gaussian window with above optimum shape parameter gives better Results where this speech activity is clearly visible. But the same is absent when using Hamming window. This speech activity visible using Gaussian window is encircled with Red mark.

Where as in the case of airport noise, the enhanced speech signal using Gaussian window looks identical with the enhanced speech signal using Hamming window. But from the objective measures with the above shape parameter values majority of the objective measures are in favour of Gaussian window.

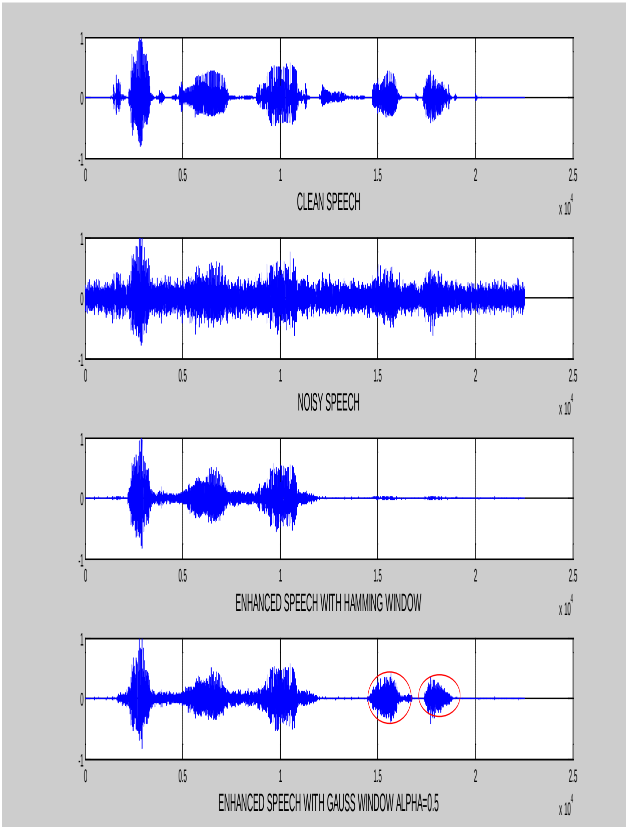

Fig. 2 (a) : Speech Signal Enhancement comparison (α=0.5, CAR-NOISE of 0dB SNR)

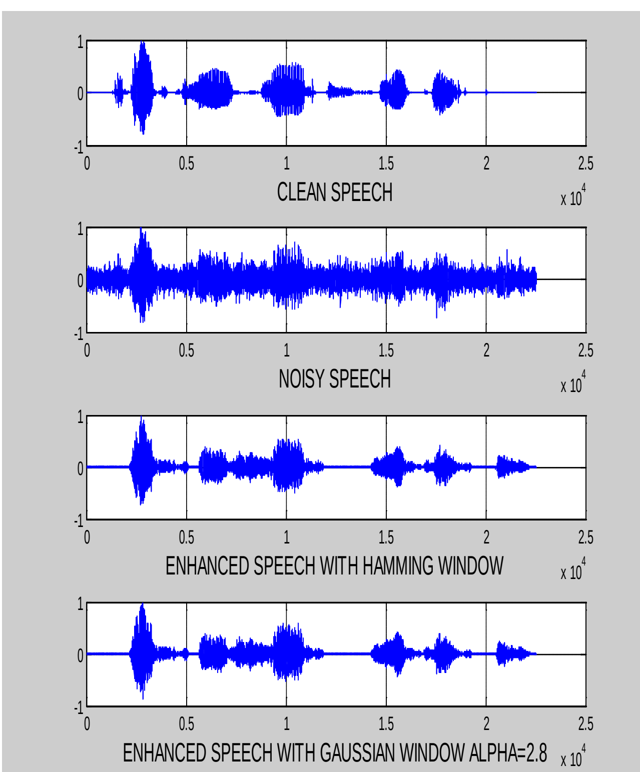

Fig. 2 (b) : Speech Signal Enhancement comparison (α=2.8, AIRPORT-NOISE of 0dB SNR)

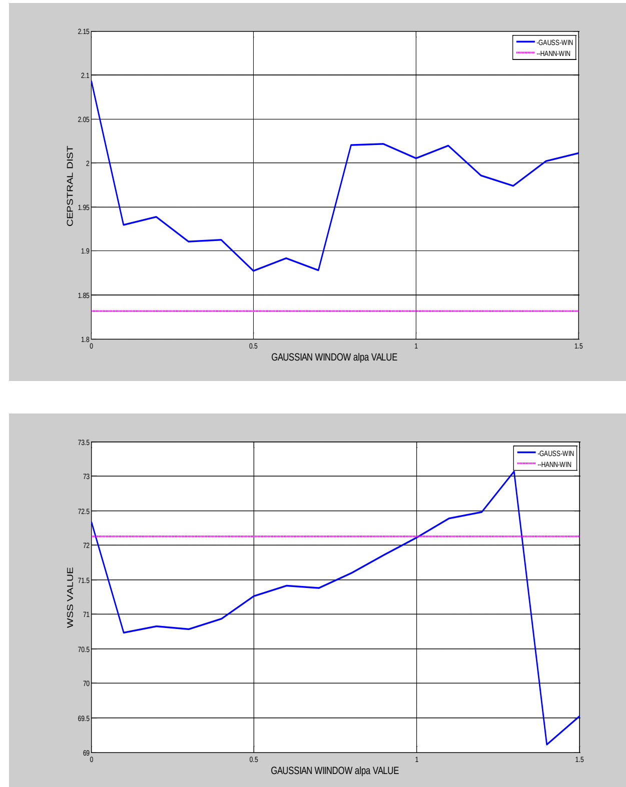

Fig. 2 (c) : Speech quality Objective Measures CEP and WSS Variation With "α", (CAR-NOISE of 0dB SNR)

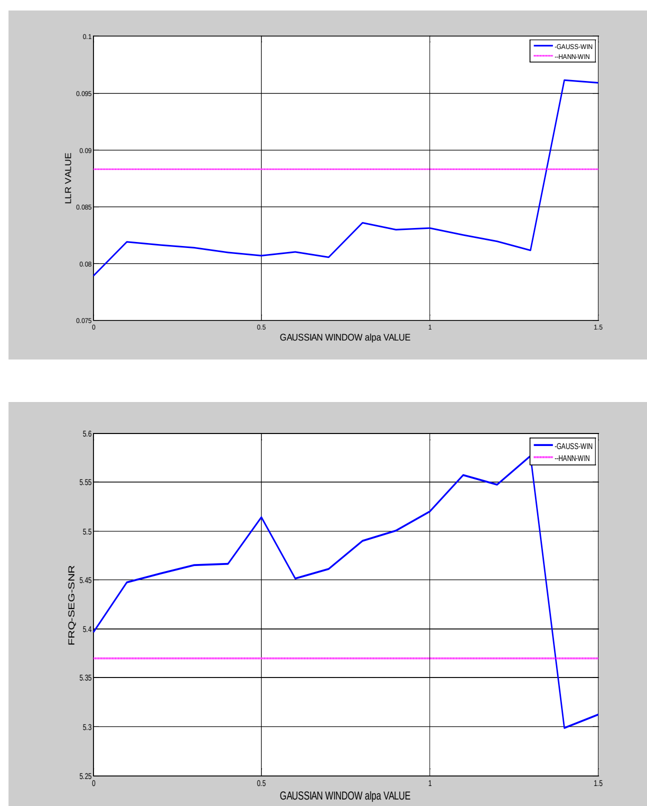

Fig. 2 (d) : Speech quality Objective Measures LLR and FSG-SNR Variation With "α", (CAR-NOISE of 0dB SNR)

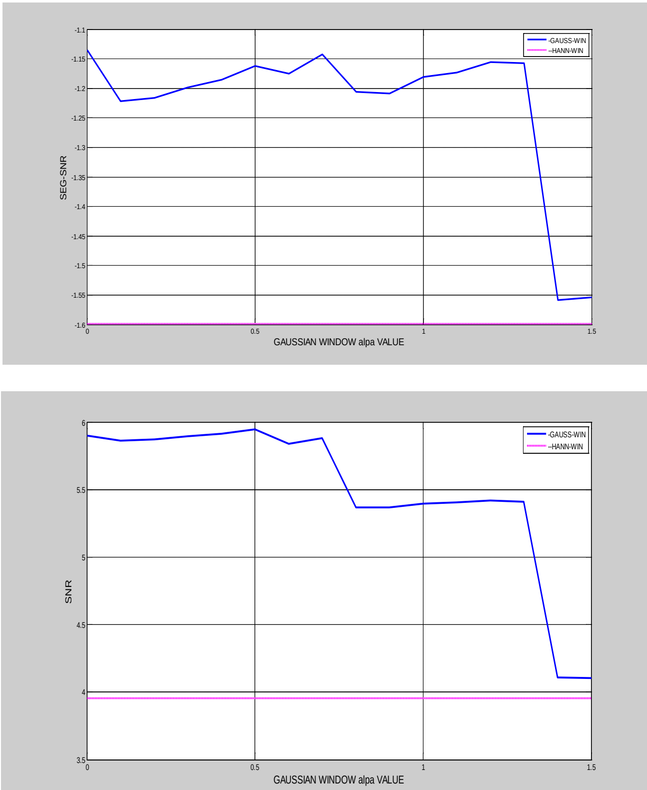

Fig. 2 (e) : Speech quality Objective Measures SEG-SNR and SNR Variation With "α", (CAR-NOISE of 0dB SNR)

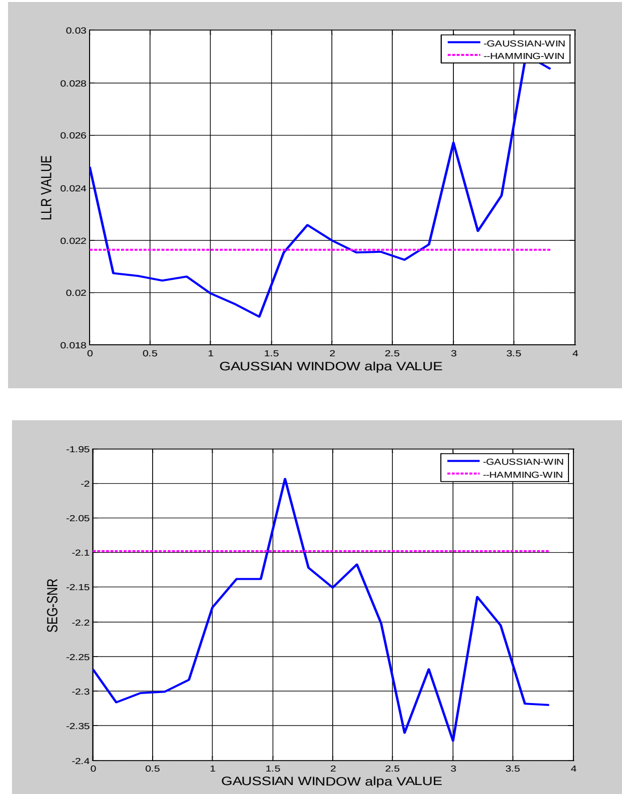

Fig. 2 (g) : Speech quality Objective Measures LLR and SEG-SNR Variation With "α", (AIRPORT-NOISE of 0dB SNR)

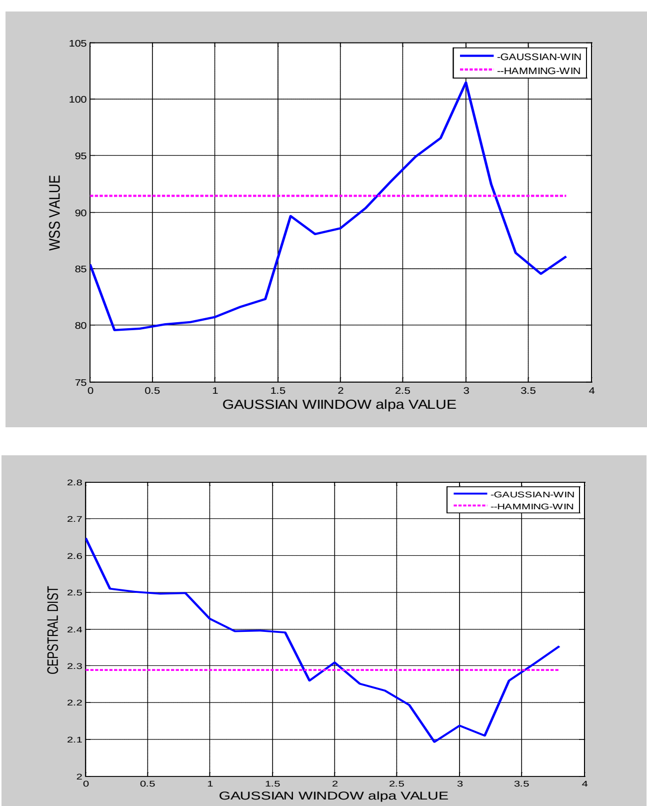

Fig. 2 (f) : Speech quality Objective Measures CEP and WSS Variation With "α", (AIRPORT-NOISE of 0dB SNR)

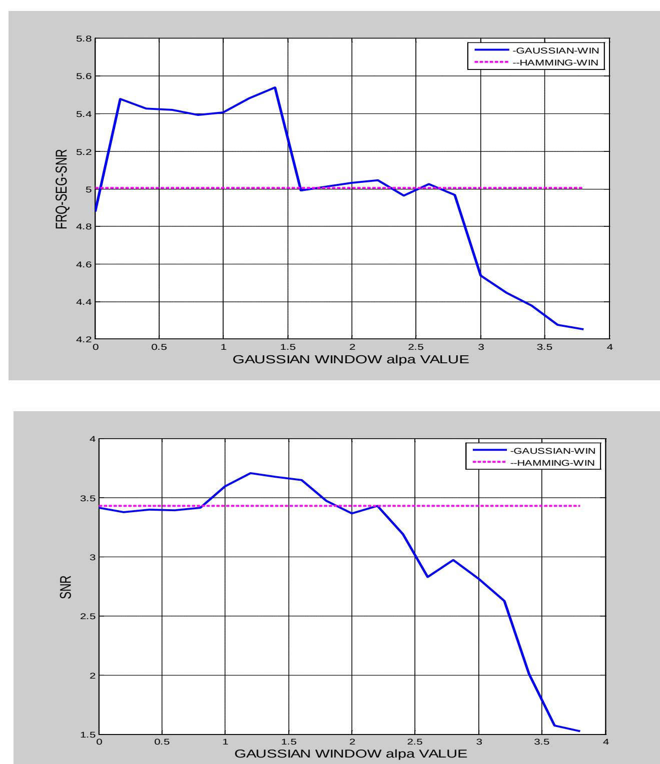

Fig. 2 (h): Speech quality Objective Measures FRS-SNR and SNR Variation With "α", (AIRPORT-NOISE of 0dB SNR)

Table 1 (a) : Variation of Objective Measures with Gaussian Window Shape Parameter "α". CAR-NOISE of 15dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.25	α=0.50	α=0.75	α=1.0	α=1.25
1	LLR	0.006	0.009	0.010	0.009	0.009	0.008	0.008
2	WSS	46.614	47.055	42.986	43.119	43.214	43.729	43.879
3	Cep	1.386	1.660	1.673	1.655	1.632	1.585	1.549
4	Seg-SNR	5.257	4.942	5.311	5.332	5.353	5.400	5.435
5	Fwseg-SNR	10.480	9.754	10.365	10.365	10.41	10.391	10.436
6	SNR	11.789	12.462	13.023	13.044	13.078	13.078	13.069

Table 1 (b) : Variation of Objective Measures with Gaussian Window Shape Parameter "α". AIRPORT-NOISE of 5dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.75	α=1.50	α=2.25	α=3.0	α=3.75
1	LLR	0.019	0.025	0.023	0.021	0.019	0.018	0.017
2	WSS	85.570	79.131	78.281	80.928	84.636	92.385	95.729
3	Cep	1.751	2.083	1.997	1.881	1.774	1.592	1.471
4	Seg-SNR	0.122	0.122	0.177	0.260	0.131	-0.020	-0.435
5	Fwseg-SNR	6.777	6.619	6.835	6.984	6.780	6.516	6.126
6	SNR	6.497	7.119	7.134	7.085	6.591	6.119	5.148

Table 1 (c) : Variation of Objective Measures with Gaussian Window Shape Parameter "α". AIRPORT-NOISE of 10dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.75	α=1.50	α=2.25	α=3.0	α=3.75
1	LLR	0.006	0.012	0.0103	0.008	0.006	0.006	0.006
2	WSS	63.324	59.279	57.040	59.917	64.340	69.122	76.522
3	Cep	1.577	1.955	1.803	1.746	1.617	1.399	1.343
4	Seg-SNR	2.581	2.465	2.706	2.710	2.600	2.335	1.563
5	Fwseg-SNR	8.912	8.414	8.768	9.027	8.780	8.376	7.449
6	SNR	9.587	9.988	10.284	10.273	9.599	8.385	6.317

Table 1 (d) : Variation of Objective Measures with Gaussian Window Shape Parameter "α".AIRPORT-NOISE of 15dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.75	α=1.50	α=2.25	α=3.0	α=3.75
1	LLR	0.005	0.009	0.007	0.006	0.005	0.005	0.006
2	WSS	52.939	50.083	46.783	48.267	52.520	60.610	71.138
3	Cep	1.373	1.733	1.665	1.565	1.425	1.265	1.214
4	Seg-SNR	4.635	4.451	4.877	4.959	4.614	3.735	2.551
5	Fwseg-SNR	10.647	9.857	10.509	10.638	10.636	9.926	8.483
6	SNR	11.635	12.166	12.819	12.777	11.726	9.497	6.806

Global Journal of Researches in Engineering (F) Volume XIV Issue VI Version I Year 2014
16

Table 1 (e) : Variation of Objective Measures with Gaussian Window Shape Parameter "α".
CAR-NOISE of 0dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.25	α=0.50	α=0.75	α=1.0	α=1.25
1	LLR	0.064	0.066	0.066	0.066	0.067	0.065	0.064
2	WSS	79.107	78.541	76.820	76.606	77.004	77.804	78.035
3	Cep	1.925	2.218	2.117	2.089	2.0710	2.049	2.038
4	Seg-SNR	-1.114	-1.277	-1.247	-1.196	-1.233	-1.188	-1.155
5	Fwseg-SNR	5.027	4.828	4.936	4.966	4.951	4.999	5.012
6	SNR	4.149	4.086	4.277	4.324	4.1907	4.229	4.305

Table 1 (f) : Variation of Objective Measures with Gaussian Window Shape Parameter "α"
CAR-NOISE of 5dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.25	α=0.50	α=0.75	α=1.0	α=1.25
1	LLR	0.036	0.039	0.036	0.036	0.035	0.036	0.036
2	WSS	66.712	66.211	63.654	62.903	62.968	63.499	63.785
3	Cep	1.731	1.969	1.848	1.819	1.769	1.797	1.800
4	Seg-SNR	0.533	0.700	0.642	0.675	0.727	0.728	0.746
5	Fwseg-SNR	6.604	6.195	6.543	6.588	6.639	6.646	6.638
6	SNR	6.351	6.863	7.141	7.160	7.182	7.179	7.173

Table 1 (g) : Variation of Objective Measures with Gaussian Window Shape Parameter "α".
CAR-NOISE of 10dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.25	α=0.50	α=0.75	α=1.0	α=1.25
1	LLR	0.013	0.014	0.014	0.014	0.014	0.014	0.013
2	WSS	55.790	55.784	51.344	51.141	51.119	50.728	51.435
3	Cep	1.540	1.825	1.759	1.754	1.733	1.716	1.676
4	Seg-SNR	3.043	2.943	3.223	3.242	3.279	3.221	3.265
5	Fwseg-SNR	8.988	8.336	8.998	9.056	9.017	9.0342	9.080
6	SNR	10.145	10.531	11.045	11.095	11.116	11.019	11.038

Table 1 (h) : Variation of Objective Measures with Gaussian Window Shape Parameter "α".
CAR-NOISE of 15dB SNR Value

S.No	Objective Measure	Hamming Window	Gaussian window with different Alpha values					
			α=0	α=0.25	α=0.50	α=0.75	α=1.0	α=1.25
1	LLR	0.006	0.009	0.010	0.009	0.009	0.008	0.008
2	WSS	46.614	47.055	42.986	43.119	43.214	43.729	43.879
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6	SNR	11.789	12.462	13.023	13.044	13.078	13.078	13.069

VII. Conclusion and Future Enhancement

Speech signal is enhanced with the help of Spectral Subtraction method using Gaussian Window with suitable shape parameter **"α"**. It is found that the speech quality in terms of the Objective measures is improved by applying the Gaussian Window with optimum shape parameter. From the figure.2 (a)-2(g), it is observed that the objective measure WSS has significant improvement for Gaussian Windowed signal when compared to Hamming Windowed signal. Majority the measures evaluated indicate that Gaussian Window with suitable shape parameter is superior to the Hamming Window in speech enhancement application using Spectral Subtraction method. It is also observed that the Window presented in this paper works out good for different types of noise, like babble, train, street and restaurant noises, at different SNR levels. Hence it may be concluded that Gaussian Window with suitable shape parameter is an attractive option compared with Hamming Window for the Speech Enhancement using Spectral Subtraction method for better Speech quality and intelligibility.

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Studies on Application of Single Crystal Diamond for Charge Particle Detection: Design, TCAD Simulations, Technology Development, & Dc Characterization

By Pourus Mehta
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Abstract- Single crystal Diamond based Charge Particle detectors have been realized through a pilot stage fabrication run at the Indian Institute of Technology-Bombay (IIT-B). Device simulations in Technology Computer Aided Design (TCAD) were employed to study the physics of charge transport within the detector. Static case simulations revealed values of critical dc performance parameters like total leakage current at applied bias as well as the intrinsic bulk resistance offered by the detector. Dynamic case simulations meant to study the effect of alpha radiation were also conducted. They indicated a certain probability of charge multiplication at low fields within the diamond crystal which needs further experimental investigation to validate. Device simulations also proved helpful in verification and validation of experimental results. Technology for fabrication of diamond detectors was developed through an iterative process spread across several runs to realize a robust device. DC characterization of the fabricated diamond detectors was performed to extract the terminal current at operating voltage (100V), intrinsic bulk resistance of the detector as well as the trend of the I-V curve.

Keywords: Technology Computer Aided Design & Single Crystal Diamond Detectors.

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STUDIESONAPPLICATIONOFSINGLECRYSTALDIAMONDFORCHARGEPARTICLEDETECTIONDESIGNTCADSIMULATIONSTECHNOLOGYDEVELOPMENTDCCHARACTERIZATION

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Keywords: Technology Computer Aided Design & Single Crystal Diamond Detectors.

I. Introduction

Single crystal Diamond (allotrope of elemental Carbon) can be used in very specialized detection applications. The wide Bandgap (5.6 eV at 300°K) property of diamond imparts it a virtually insulating character at room temperature. This translates into a negligibly low thermal carrier generation rate at room temperature. Thus resulting in very low leakage currents at operating temperatures, in-turn ensuring a low background for the signal and higher quantum efficiency.

For purpose of application of diamond as a detector material, it has to be connected to the electrical circuit. This is normally done by creating metallic contacts on the cubic planar diamond sample by certain specialized methods [1-5]. The fundamental principle behind formation of Ohmic contacts over diamond is to match the work function of the diamond with that of the contacting metal over it.

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The work function of diamond being ~ 5eV is within the range of work functions of metals like Titanium (4.33 eV) & Tantalum (4.22 ± 0.06 eV). Hence, either Titanium or Tantalum could be used to make direct contact with diamond films. Additionally, gold films are also deposited over these Ti/Ta films for increased robustness in wire-bonding.

Single crystal Diamond samples were grown by microwave decomposition of methane gas [7]. A piece of single crystal natural diamond was employed as seed for deposition of carbon atoms in a diamond matrix. The seed crystal was then separated from the epitaxially grown crystal through laser ablation technique. This single crystal diamond sample formed the starting material for realizing Alpha Particle detectors. Proto-type Diamond detectors were realized through a fabrication run at the Electrical Engineering Department, Indian Institute of Technology-Bombay. The technology for fabrication of electrical contacts over diamond crystals was developed through an iterative process. DC characterization of the fabricated devices was performed to establish the current to voltage relationship as well as to know the bulk resistance of the detector.

Additionally, the physics of the alpha particle detection in diamond was studied employing simulation studies in Technology Computer Aided Design (TCAD). The Silvaco Atlas TCAD device simulation suite was employed to perform the simulation studies. The dc characteristics of the detector were simulated to extract the dc bulk resistance of the detector. Dynamic characteristics were simulated by incorporation of a charge cloud equivalent to a deposited energy of 5.5 MeV at a designated lateral distance and time over the two-dimensional cross-section of the diamond detector (Fig. 2). The output (anode) current pulse w.r.t. time was extracted to study the mechanism of charge carrier transport within the bulk of the detector. Additionally, the energy band diagram in diamond was extracted and confirmed the resistive nature of response in the detector.

II. Detector Design

Diamond substrates having dimensions 2 x 2 x 1 mm^3 were grown by microwave ionization of methane

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gas. The first proto-type of diamond detectors (Fig. 1) essentially consisted of a cubic piece of single crystal diamond with two electrical contacts on its opposite faces. The process of formation of electrical contacts is enumerated in section 4. These detectors are electrically resistive in character.

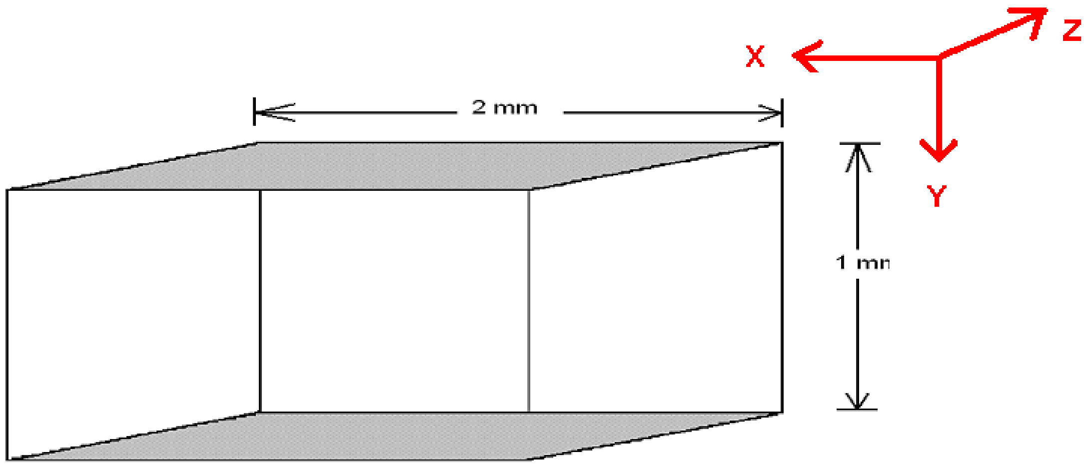

Fig. 1 : 3-Dimensional illustrative view of the fabricated Diamond detector

III. Device Simulations

a) Design & Methodology

Device simulations (Static & Dynamic) were performed to derive the static & dynamic characteristics of the Diamond detector employing the Silvaco Atlas TCAD simulation suite.

A p-type, high resistivity, 1 mm thick Diamond substrate forms the starting material for the diamond detector fabrication. To begin with, a virtual 2-dimensional cross section of the device had to be defined with the lateral dimension of the diamond structure parallel to the X-axis and the thickness of the crystal to the Y-axis. The 2D cross-section is then further sub-divided into rectangular unit cells by definition of a mesh/grid structure which covers the entire physical simulation domain. Meshes can be of three types viz. rectangular, cylindrical and triangular. The first two types are defined in two dimensions whereas the cylindrical mesh can only be defined in 3D structure. A rectangular mesh is essentially a matrix of horizontal and vertical lines spaced at pre-defined distances across the entire physical space. Specification of mesh involves a trade-off between the requirements of accuracy, numerical efficiency & time economy.

A good degree of accuracy demands definition of a finer mesh to resolve minute features of the structure. Time economy entails the requirement of a coarse mesh to minimize total number of grid points and reduce simulation time. Mesh definition is something that requires sufficient skill and experience in understanding the finer nuances of using the simulation tool. Some of the guidelines that can be helpful in creating a good grid are as follows.

- A mesh should be such that it has the minimum number of grid points to provide the required accuracy at the same time does not have too many excess points which impose a cost on time economy.
- During mesh generation there is fair probability of generating obtuse triangles which can impair accuracy, convergence, and robustness. Hence, the mesh should be defined in such a way so as to minimize the number of obtuse triangles (preferably $< 1\%$ of number of triangles).
- While defining a mesh, care should be taken to minimize long thin triangles which create problems of convergence.

After definition of a mesh there are sufficient provisions to improve the mesh to achieve accuracy and time economy. Mesh improvement algorithms have to be employed to improve inconsistencies in a coarse mesh. There are two techniques available for mesh refinement viz. node smoothing and triangle smoothing. With node smoothing, several iterative passes are carried out during, which each node is moved to a position and improves the angles of the triangles surrounding it. Node smoothing should only be used for grids that are already irregular. If node smoothing is used for nearly rectangular grids, it may significantly degrade the quality of the mesh.

In triangle smoothing (which is also referred to as diagonal flipping), each adjoining pair of triangles is examined. If appropriate, the diagonal of the quadrilateral is flipped to stabilize the discretization. The diagonal is never flipped when two elements are composed of different materials. Triangle smoothing is desirable in almost all cases, and should be performed on both the initial grid and in subsequent regrid regimes. There is fair probability of generation of errors associated with a mesh generation which can be eliminated by systematically repeating the calculation using a sequence of progressively finer meshes. The typical approach is to adequately resolve structural features, including doping, with an initial or base mesh, and then add nodes as required to resolve significant features of the solution. Definition of meshes in ATLAS can be through various routes. Firstly, a pre-generated mesh used in a process simulation program can be directly inherited into the device simulator. Secondly, meshes can be defined analytically by specification of X-Y co-ordinates of every point in the 2 dimensional cross-section which gives greater grid control to the designer.

Mesh can also be generated through a special purpose device generation utility called DEVEDIT available in the tool which is a GUI based program that can employed to interactively define the meshes together with definitions of the various regions of the device. The mesh for the 2D structure of the diamond detector was generated with a maximum of 20,000 grid points (grid point limit). The grid density worked out to be 0.01 points/Area, which was the maximum possible density for this structure. The 2-dimensional cross-section of the diamond detector is illustrated in Figure 2.

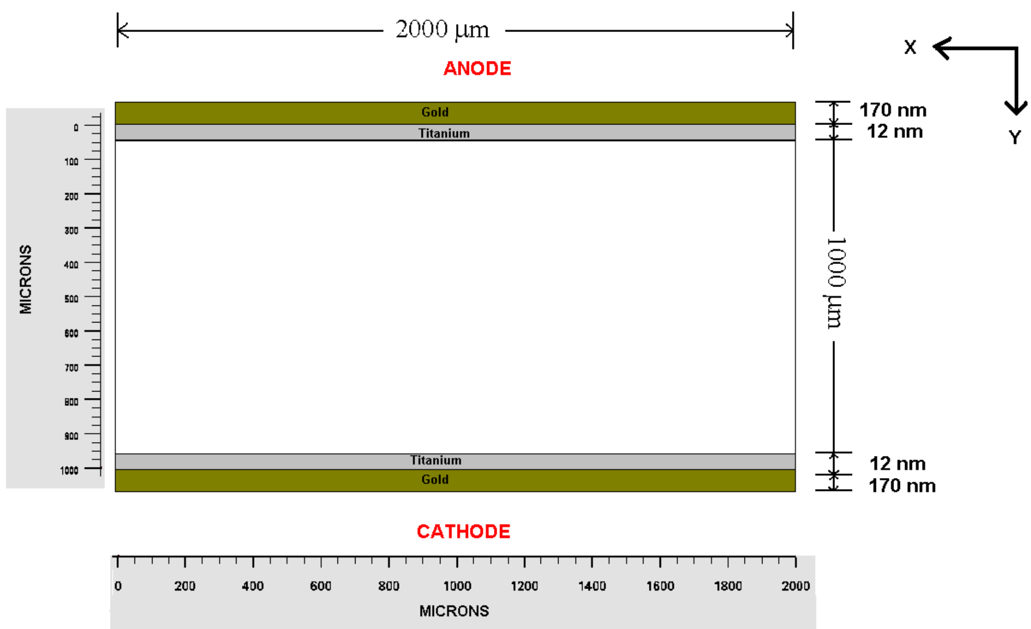

Fig. 2 : 2-Dimensional cross-section of the Diamond detector

Once the mesh has been generated and tuned for good accuracy, the next job is to define various regions like diamond, metals, etc. at specific locations of the 2-dimensional cross-section. As seen from figure 2, the diamond substrate is defined by a rectangle from x = 0 µm - 2000µm and y = 0 µm - 1000 µm. Metallic contacts were defined over both the top (y = 0) and bottom faces (y = 1000).

Boron exists in natural Diamond as an acceptor impurity (E_{av} =0.37eV) on a substitutional site. To incorporate this, boron dopant needs to be defined within the semiconductor bulk. The p-type impurity was incorporated within the bulk of the diamond lattice with a uniform doping concentration of $5.43x10^{7}$ cm^{-3} along the depth. The one dimensional doping profile along the depth (Y-direction) of the device is illustrated in figure 3. Subsequently, electrical contacts were formed by titanium deposition at the top and bottom surfaces of the diamond crystal to form Anode and Cathode electrodes respectively.

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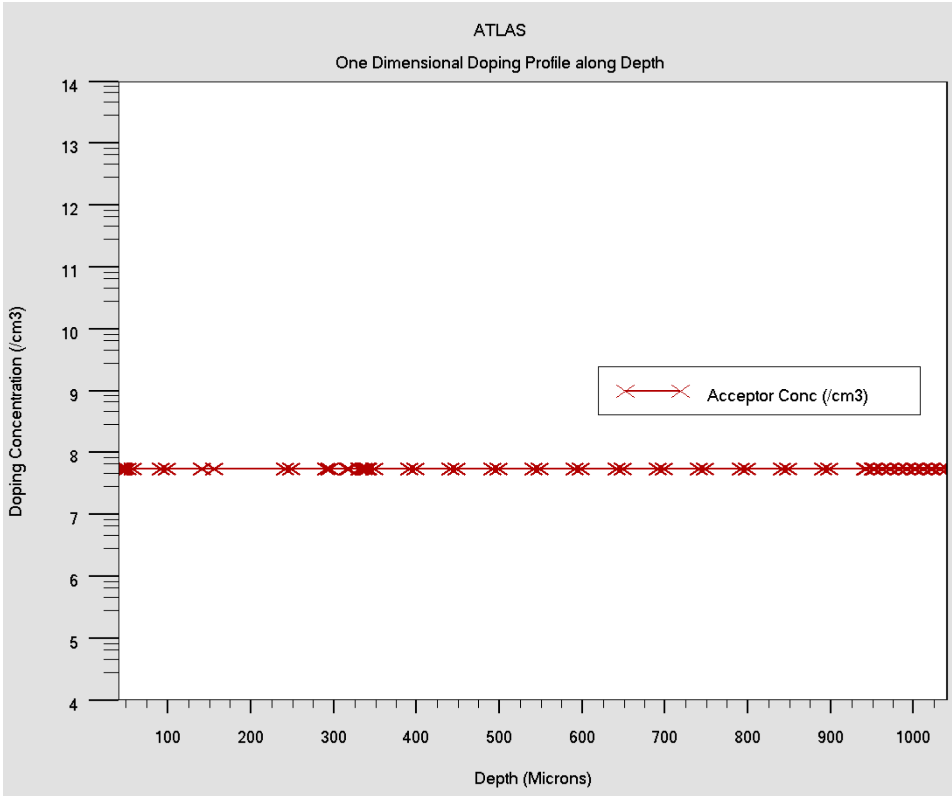

Fig. 3 : One dimensional doping profile along depth of the device

Once the device structure was generated with required number of mesh points and electrodes for applying biases, simulations for studying the current to voltage relationship (static case) could commence. I-V simulation requires the definition of certain parameters like minority carrier lifetime, e-h mobility, models etc. at the input.

An optimized value of minority carrier lifetime of 5 ms was achieved for which the total current at 100V applied bias was 80nA as was the case in experimental I-V characteristics. Similarly, the values of Electron and Hole mobility were set to 500 $cm^2/V.s$ and 300 $cm^2/V.s$ respectively by iterative derivation and matching I-V curves from simulation with experiment.

Processes of generation-recombination restore the semiconductor material to equilibrium after the perturbation force ceases to exist. A homogeneously doped semiconductor with carrier concentrations n and p to the equilibrium concentrations $n0$ & $p0$ then at equilibrium a steady state balance exists according to law of mass action.

$$n_0\, p_0 = n_i^2 \tag{1}$$

The processes responsible for generation-recombination can be broadly categorized into phonon transitions, photon transitions, Auger transitions, surface recombination, impact ionization & tunneling. Phonon transitions occur in the presence of a trap (or defect) within the forbidden gap of the semiconductor. This is essentially a two step process, the theory of which was first derived by Shockley and Read and then by Hall. The Shockley-Read-Hall recombination is modeled as follows.

$$R_{SRH} = \frac{pn - n_{ie}^2}{\mathrm{TAUP0}\left[n + n_{ie} exp\left(\frac{\mathrm{ETRAP}}{kT_L}\right)\right] + \mathrm{TAUN0}\left[p + n_{ie} exp\left(\frac{-\mathrm{ETRAP}}{kT_L}\right)\right]} \tag{2}$$

Where ETRAP is the difference between the trap energy level and the intrinsic Fermi level, TL is the lattice temperature in degrees Kelvin and TAUN0 and TAUP0 are the Electron and Hole lifetimes. T_L is the lattice temperature, p & n the hole and electron densities resp. The Shockley Read Hall and Auger recombination models pertaining to generation/recombination processes were incorporated.

Carriers (Electrons/holes) get accelerated by application of electric fields. There are inherent mechanisms in nature to restore balance in materials. These processes scatter the accelerated charges and dissipate the energy and thus leading to a reduction of linear momentum. Scattering mechanisms can be broadly classified as lattice scattering (phonons assisted) and impurity scattering. The cumulative effect of all these restoring mechanisms on the macroscopic scale leads to a reduction in overall mobility of carriers. Mobility models are defined for low-field behavior & high field behavior. The low electric field behavior pertains to carriers being near equilibrium. The high electric field behavior shows that the carrier mobility decreases with increase in electric field. The mean drift velocity no longer increases linearly with increasing electric field, but saturates to a value denoted by V_{SAT}.

The field dependent mobility is related to the low field mobilities (μ_{n0} and μ_{p0}) according to the following equations.

$$\mu_n(E) = \mu_{n0}\left[\frac{1}{1+\left(\frac{\mu_{n0}\,E}{\mathrm{VSATN}}\right)^{\mathrm{BETAN}}}\right]^{\frac{1}{\mathrm{BETAN}}} \tag{3}$$

$$\mu_p(E) = \mu_{p0}\left[\frac{1}{1+\left(\frac{\mu_{p0}\,E}{\mathrm{VSATP}}\right)^{\mathrm{BETAP}}}\right]^{\frac{1}{\mathrm{BETAP}}} \tag{4}$$

Where "*E*" *is* the parallel electric field and μ_{n0} and μ_{p0} are the low-field electron and hole mobilities respectively. Modeling mobility in bulk material involves: (i) characterizing μ_{n0} and μ_{p0} as a function of doping and lattice temperature, (ii) characterizing V_{SAT} (Saturation Velocity) as a function of lattice temperature, and (iii) describing the transition between the low-field mobility and saturated velocity regions. The parallel Field Dependent Mobility model (Equations) was incorporated which constitutes the modeling of velocity saturation effects in high field devices.

Numerical solutions to the Poisson and continuity equations (Eq.) now need to be deduced.

$$\nabla \cdot \nabla V = \frac{\rho}{\varepsilon} \tag{5}$$

where:

V = Electrostatic potential

ε = local permittivity

ρ = local space charge density.

$$\frac{\partial n}{\partial t} = \frac{1}{q}div\vec{J}_n + G_n - R_n \tag{6}$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}div\vec{J}_p + G_p - R_p \tag{7}$$

Where:

n = Electron concentration

p = Hole concentration

J_n = electron current density

J_p = Hole current density

Gn = Electron generation rate

Gp = Hole generation rate

Rn = Electron recombination rate

Rp = Hole recombination rate

q = magnitude of the charge on an electron.

There are various numerical methods like Newton (Block & Autonr), Gummel, etc. which can be employed. The Newton-Richardson Method is a variant of the Newton method that calculates a new version of the coefficient matrix only when slowing convergence demonstrates that this is necessary. An automated Newton-Richardson solution can be deduced by invoking the AUTONR parameter available in ATLAS, which improves performance significantly. Convergence is the primary prerequisite for achieving accuracy in numerical solution to the problem. Various strategies like bias update size reduction can be employed to achieve convergence quickly. Newton's method is the default for drift-diffusion calculations in ATLAS as it is fairly accurate in dc, transient, curve-trace analysis & frequency-domain small-signal analysis.

Subsequently, certain boundary conditions viz. Ohmic, Schottky, insulated and Neumann (reflective) need to be specified for definition of the electrical nature of biasing electrodes. Voltage and current boundary conditions are normally specified at most kinds of electrodes. In this case, both electrodes (anode & cathode) were attributed to a voltage boundary condition to simulate Ohmic nature of these electrodes as in actual measurement. Poisson and continuity equations were solved at every grid point with appropriate initial guesses using Newton-Richardson method. The dc voltage on the anode was ramped from 0 V to +100 V keeping the cathode at ground potential. The dc characteristics were extracted for the first quadrant of the I-V characteristics. Subsequently, a reverse bias of -100V was applied to the anode to simulate the nature of the I-V in reverse direction.

In the dynamic simulations case, special charge generation models had to be incorporated to emulate charge carrier generation by sub-atomic charge particles in Diamond. An alpha particle incidence simulation was performed employing the Single-event-upset (SEU) command set for emulating a charge density within the active volume of the diamond crystal. SEU command line features options in controlling various parameters of the simulation. An alpha particle track of specific radius (R) and energy can be defined to pass through the cross-section of the device at a designated X location and for a specific track length in Y direction. Electron/hole pairs generated at any point are a function of the radial distance "**r**" from the center of the track to the point, the distance "**l**" along the track and the time of incidence "**t**". The implementation into ATLAS allows definition of the generation rate as the number of electron-hole pairs per unit volume along the track according to the following equation.

$$G(r,l,t) = DENSITY * L1(l) + S * B.DENSITY * L2(l) * R(R) * T(t) \tag{8}$$

DENSITY and B.DENSITY are defined as the number of generated electron/hole pairs per cm^3. Scaling factor denoted by "**S**" is given by the following equation.

$$S = \frac{1}{q\pi RADIUS^2} \tag{9}$$

The factors L_1 and L_2 are defined according to equation.

$$L_1(l) = A_1 + A_2 * l + A_3 e^{A_4 * l} \tag{10}$$

$$L_2(l) = B_1(B_2 + l * B_3 l)^{B_4} \tag{11}$$

Parameters A_1, A_2, A_3, A_4, B_1, B_2, B_3, and B_4 are user-definable and can be tuned for optimization purposes.

An alpha particle track of 1μm radius was defined at a distance of 500μm from the leftmost edge of the device in the X-direction (500,0.0,0.0; 500,21.0,0.0). The e-h pair number density (N_o = Number of e-h pairs / Volume) was fixed to be 6.419 x 10^{15} cm^{-3} corresponding to a volume of 6.59 x 10^{-11} cm^3 for an alpha particle track length of **21 μm** in Diamond [Range of 5.5 MeV Alpha in Diamond = 21 μm (SRIM Database)]. The simulation was performed for a total time of 100 μs with an alpha particle incidence time being 10 pico-seconds and a pulse width of 1.28 pico-seconds corresponding to the **21μm** trajectory in diamond. All material specific parameters like lifetime, mobility etc. remained the same as in the static simulation case. Models pertaining to mobility and generation/ recombination were the same as in the static simulation case.

Prior to running the iterative solver for alpha particle incidence, the dc solution for an applied bias of 100V had to be obtained using the static simulation regime already explained previously. Once the detector was biased at 100V, a transient simulation could be performed for the dynamic case. A time variant simulation was performed for a total simulation time of 100μs. Time steps were tuned in a way to provide finer (0.2ps) time variation at time of alpha incidence for better accuracy in resolution of the dynamic behavior of the device. Solutions were obtained using the Newton method with additional specification of minimum (10fs) & maximum time step (0.2ps) for the entire simulation. At various stages output files were generated to obtain parameters like electric field, electron/hole velocity, electric field lines/vectors, electron and hole current densities & conduction/valence band edges.

b) Results & Discussions

The 2D cross-section of the diamond detector [Fig. 2] has been subjected to application of appropriate voltages and suitable boundary conditions (discussed in previous section) to ensure that the solution to the Poisson & continuity equations converged. Biases were applied such that the back-cathode was at a zero potential whereas the anode potential was varied from -100 V to 100 V. Application of such biasing scheme developed a linear potential distribution along the depth (Fig. 2: Y-direction) of the detector. The reciprocal of slope of simulated I-V (Fig. 6) curve gave the bulk resistance which worked out to be **1.3 GΩ**. The trend of the I-V characteristic was linear indicating an Ohmic nature of the dc response of the detector. The two-dimensional potential contour plot (Fig. 4) showed a linear gradation of the potential along the depth of the detector whereas across the lateral dimension (Fig.4: X-direction) it is equipotential in nature. The electric field vector plot (Fig. 5) shows a vector direction pointing from anode to back-cathode indicating an electron movement from cathode to anode.

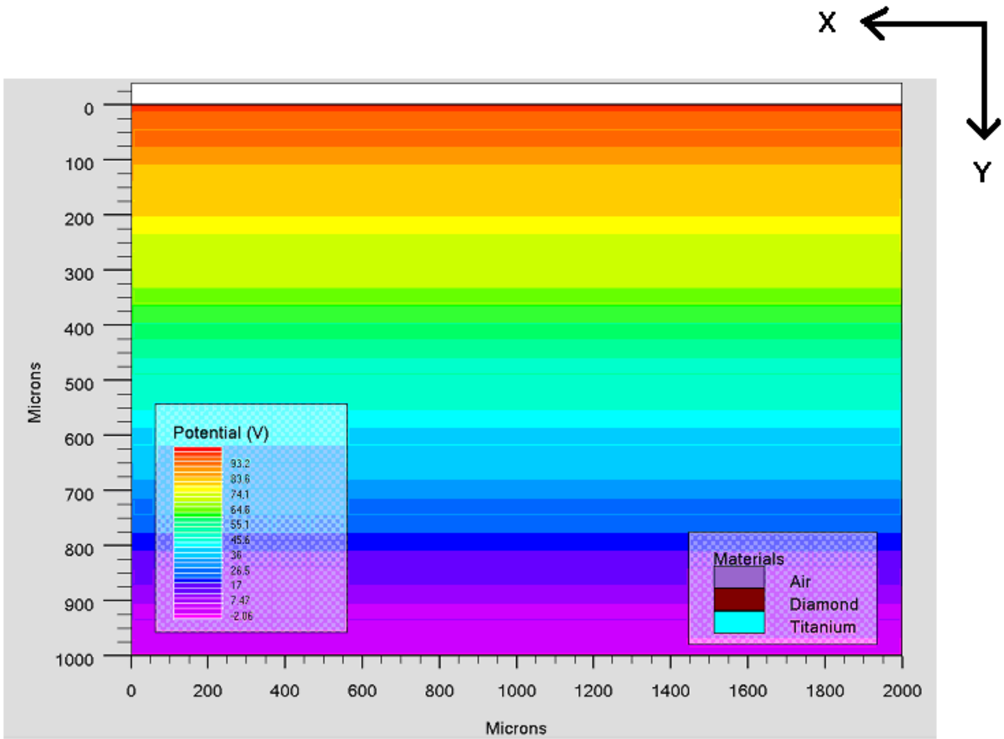

Fig. 4 : 2-D Potential contours within the diamond detector

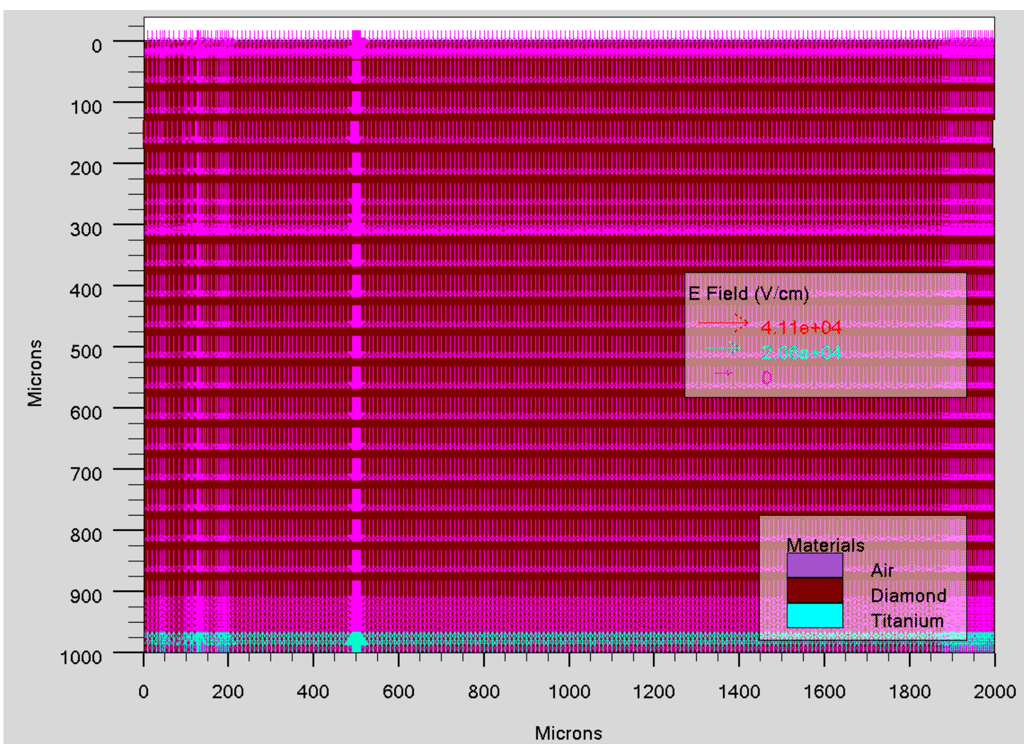

Fig. 5 : 2-D Electric Field vector plot within the diamond detector

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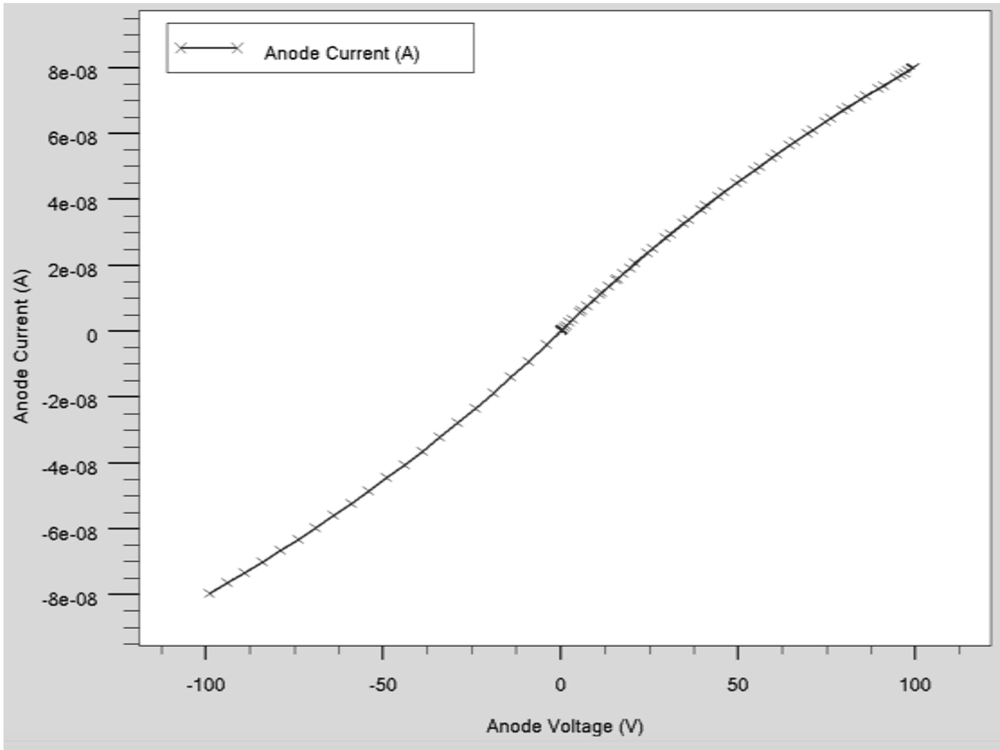

Fig. 6 : Simulated I-V characteristics of the diamond detector

The second rung of simulations was performed to parameterize the dynamic response of the diamond detector to alpha radiation. An alpha particle pulse simulation was performed by defining an ionization charge track of 1μm radius at a lateral distance (X-direction) of 500μm from the leftmost edge of the cross-section. The number of generated electron-hole pairs analytically worked out to be 4.23 x 10^5 corresponding to an alpha energy of 5.5 MeV (e-h pair generation energy in diamond = 13eV). The photo-generated electrons got swept across the constant Electric Field (1000 V/cm) towards the anode (+ve Electrode) for an applied potential difference of +100 V w.r.t back-cathode. Corresponding to the field strength of 1000 V/cm & Electron Drift Velocity of 5×10^5cm/s, the Electron Mobility worked out to be 500 $cm^2/V.s$ at 300°K. This implied a total response time (Drift Time) of 200ns for a drift distance of 1000 μm (thickness of substrate).

Dynamic simulations gave the dynamic current output of the detector at the anode as shown in figure 7 (a). The incident alpha particles underwent a columbic interaction with diamond resulting in ionization of the target material along the track. The anode current characteristics (Fig. 7a) showed two distinct features, the first one began at 8 ps and peaked at 12 ps to a value of 0.65 mA above the dc baseline of 80 nA at 100 V applied bias. The first feature (fast-component) is due to the collection of alpha generated electrons at the top-surface which is exposed to the alpha radiation. The area under the curve of the first feature of the current pulse resulted in a deposited a total charge of 64.8 fC within the bulk of the diamond lattice (Fig. 7-a). Figure 8 displayed the value of deposited charge to be 67.5 femto-Coulomb. The analytically derived alpha deposited charge worked out to be 65 femto-Coulomb which was in good agreement with that derived from simulation (Fig. 8).

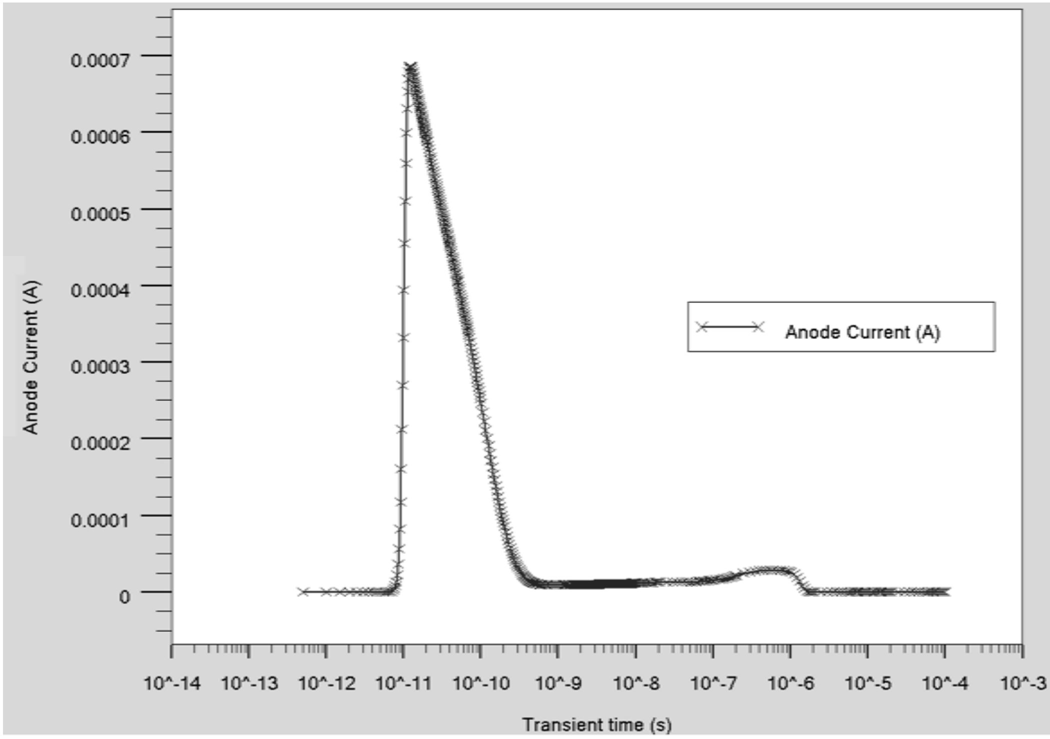

Fig. 7 (a) : Anode current pulse output response for alpha particle incidence

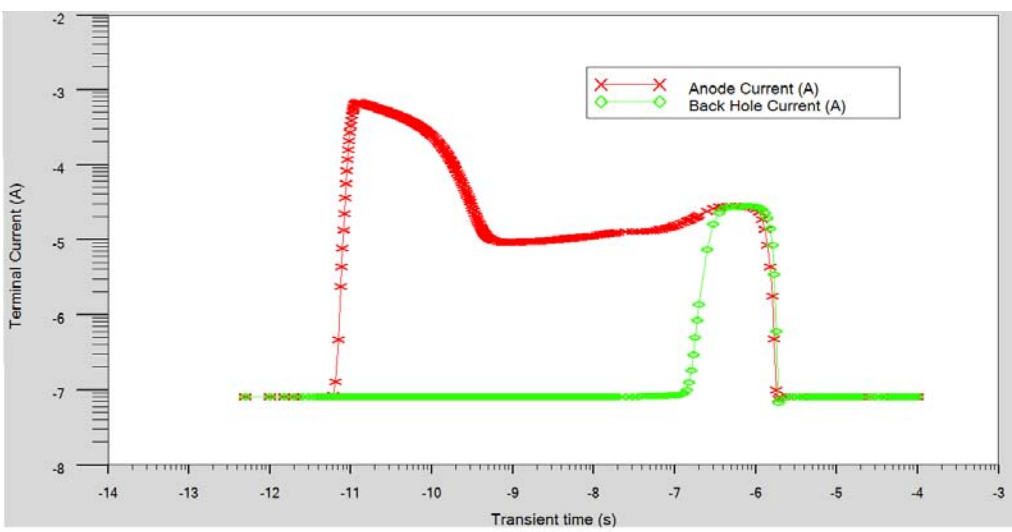

Fig. 7 (b) : Overlay plot of Anode current and back Hole current

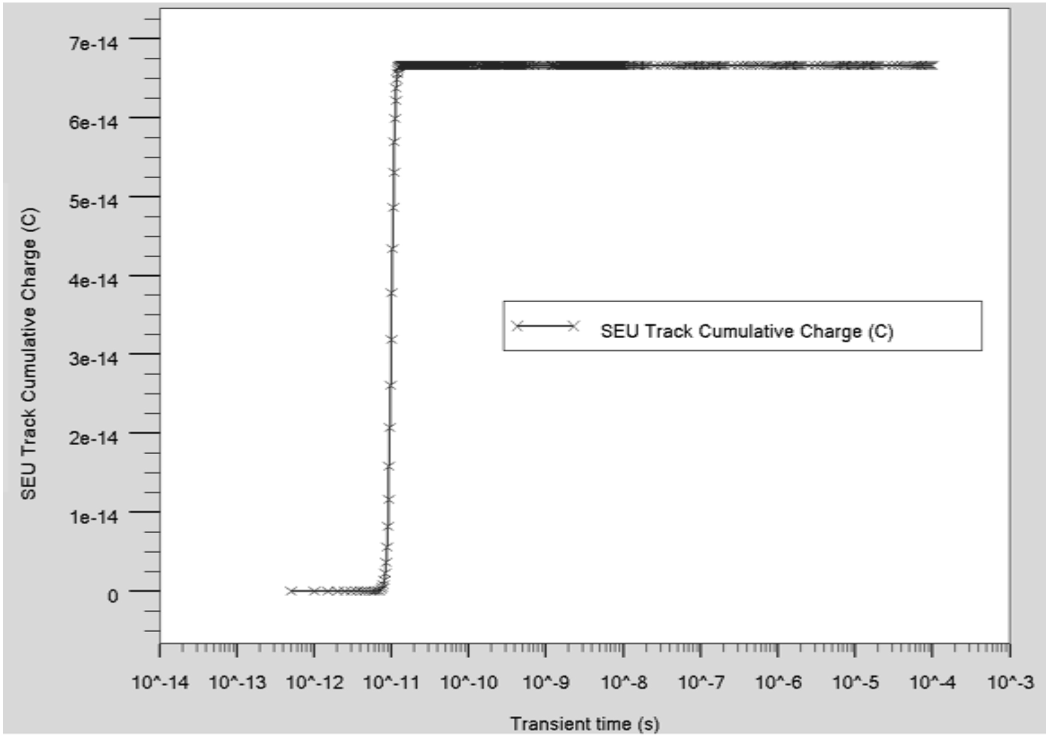

Fig. 8 : Total charge deposited by Alpha particle along its track in the detector

The second feature of the alpha characteristics (slow-component) begins to develop at 100 nano-second and attains a value of 30µA at a time of 1 µs. The second feature of the anode current pulse characteristics can be attributed to the drift and ultimate collection of holes (primary ionization charges) at the back-cathode.

The total area under the curve for the anode pulse characteristics (including slow and fast components) worked out to be 41 pico-Coulombs. This value of charge was very much higher than deposited primary charge of 67 femto-coulombs indicating the probability of existence of secondary ionization within the bulk of the diamond lattice. The simulated current pulse showed a good resemblance to the experimentally derived pulse displayed in reference 10. The probability of secondary ionization can be higher for holes due to their higher effective mass as compared to electrons at the same energy. Figure 7(b) shows that the slow component at 1 µs is entirely contributed due to the collection of generated holes at the back electrode. The calculated charge gain factor worked out to be 611 per deposited primary hole. Further exhaustive experimental studies are required to prove the proposed concept of charge multiplication within diamond lattice at low field.

The total collection time for the entire generated charge (primary and secondary) was 2.5 micro-seconds at a detector bias of 100V. The electron current density contours and vector plots (Figs. 9 & 10) showed a peak density at the point of alpha particle incidence (500µm) along the lateral dimension of the detector. This confirmed the existence of alpha particle induced electron-hole pair generation within the bulk of the detector. The energy band diagram (Fig. 11) in the bulk of the diamond is linear and maintains a band-gap of 5.5eV which confirms a resistive response for the detector.

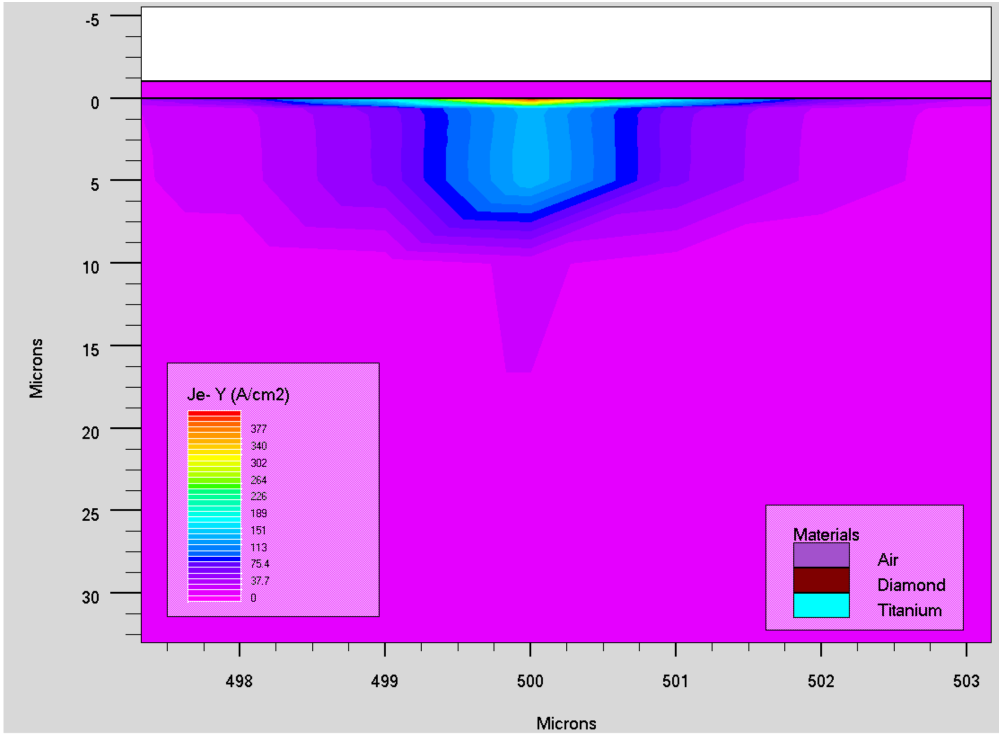

Fig. 9 : Zoomed illustration showing Electron current density contours within the detector

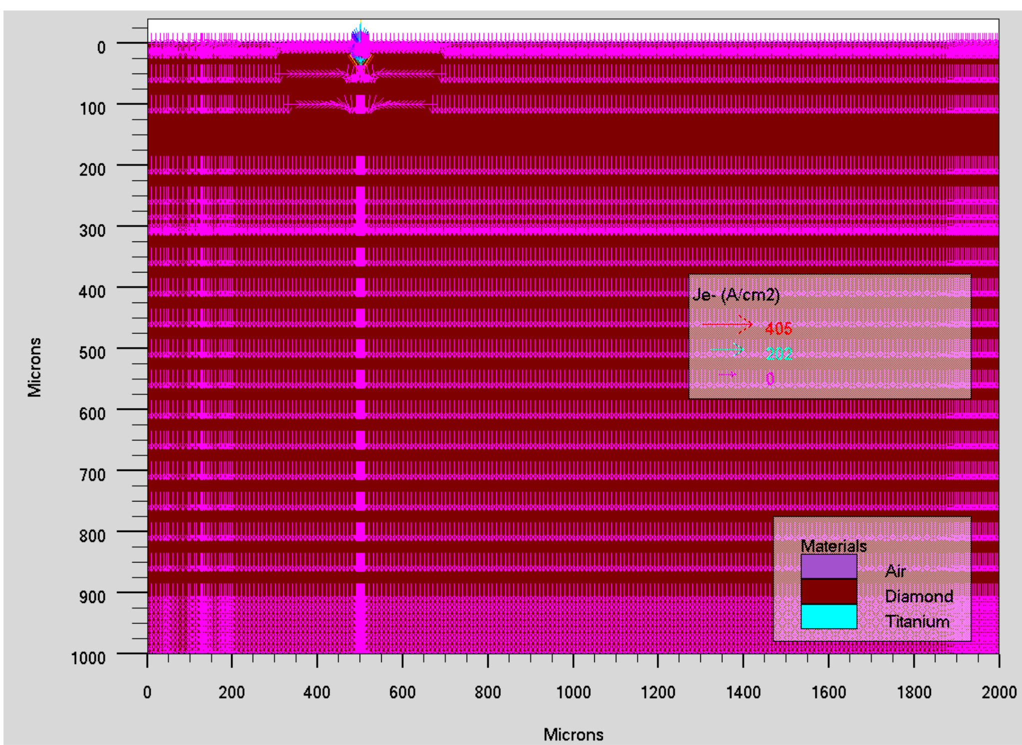

Fig. 10 : Electron current density vectors within the detector

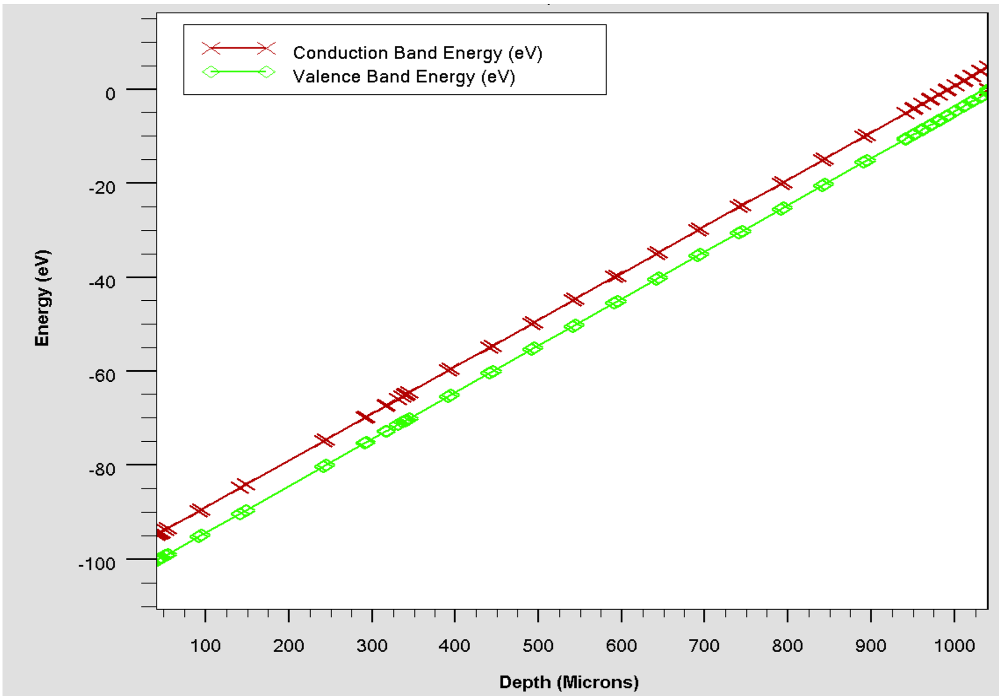

Fig. 11 : Energy Band diagram within the detector

IV. Technology Development

Single-crystal Diamond samples were grown using Plasma assisted CVD technique, over a commercial, <100> oriented polished single-crystal diamond substrate [7]. Prior to undergoing any growth process, these single crystal diamond substrates were subjected to hydrogen plasma treatment for surface topology linearization. Subsequently, the growth of <100> oriented carbon mono-layers in a diamond matrix was initiated at a temperature of 1000°C employing 8% methane as precursor gas in a hydrogen ambient, at 140 Torr of total gas pressure. The growth rates varied from 10-15 μm/h depending on a microwave power variation from 1 and 2kW.

This sample of single crystal diamond formed the starting material for detector development. A 12 nm thick Titanium film was deposited over the Diamond crystal by plasma sputtering technique (Nordiko Sputter System). This was followed by deposition of a 170 nm thick gold film over the existing Titanium film for reasons discussed earlier. Subsequently, the crystal metallized on both opposite faces was subjected to annealing treatment at 775°C for 60 minutes in nitrogen atmosphere to prevent the high temperature allotropic transformation of diamond to graphite. Titanium forms Titanium Carbide after reacting with diamond. This lead to a minimization of the work function difference between diamond and Ti and in turn imparting Ohmic character to the contact. Other methods of Ohmic contact formation were not feasible as they required the boron implantation facility which was unavailable on site.

V. Dc Characterization

a) Objectives & Measurement Methodology

I-V characterization of the diamond detector was performed to extract the *dc* leakage current across the device at room temperature. The leakage current forms the *dc* baseline of the alpha particle generated pulse in the detector. The dimensions of the diamond crystal being small, handling became quite an issue. To prepare the detector for characterization required the manufacture of a special enclosure/Test-zig (Fig. 12) to house the device. The enclosure was essentially a cylindrical cavity with a lid to which a co-axial BNC connector was attached. The outer casing of the BNC connector was electrically connected to the metallic enclosure. The central electrode of the BNC was attached to a gold coated copper probe at its extremity. The diamond detector was placed with one of its gold-coated electrodes making contact with the bottom face of the cavity and placing the lid over the cavity biased the top gold-coated electrode. The required bias was applied to the central electrode of the BNC connector w.r.t the external casing which was being held at ground potential. A Keithley 2400 source-measure unit (SMU) was employed to bias the detector. A computer based GPIB program was coded to run the automated dc I-V characteristics.

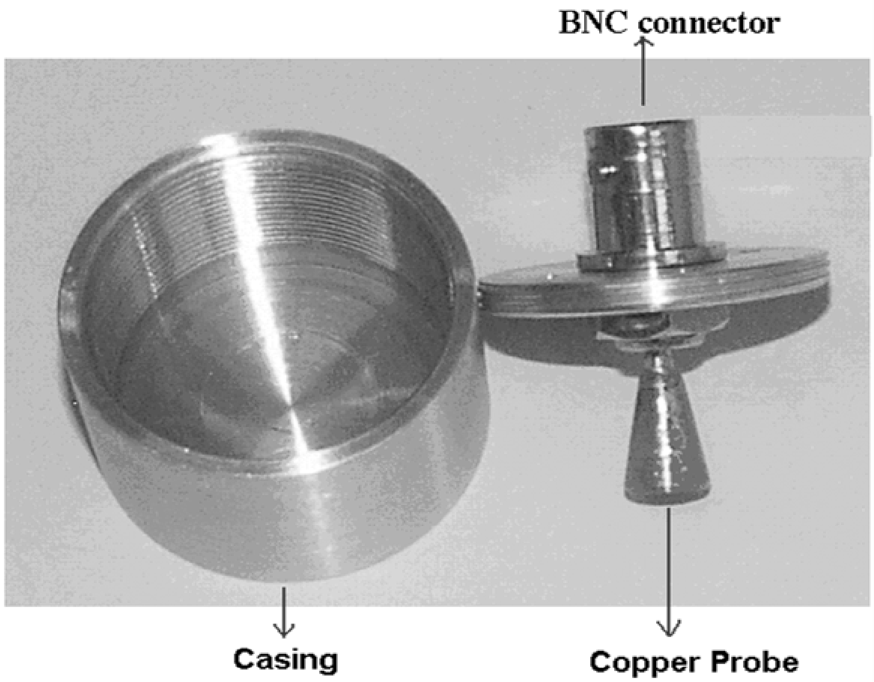

Fig. 12 : Photograph of the enclosure (Test-zig) housing the diamond detector for Characterization

b) *Results & Discussions*

Dc applied voltage was ramped from –100 to + 100 Volts and the current across the detector was measured for each voltage step. As seen from figure 13 the current voltage characteristic shows essentially a perfect Ohmic behavior. This means that the diamond detector is resistive in its response to voltage. The reciprocal of slope of the I-V curve gave the value of intrinsic (bulk) resistance of the detector, which worked out to be 1.3 GΩ in this case. The leakage current even at 100 volts of applied bias was merely 82 nA, in-turn ensuring a low leakage background for the alpha signal.

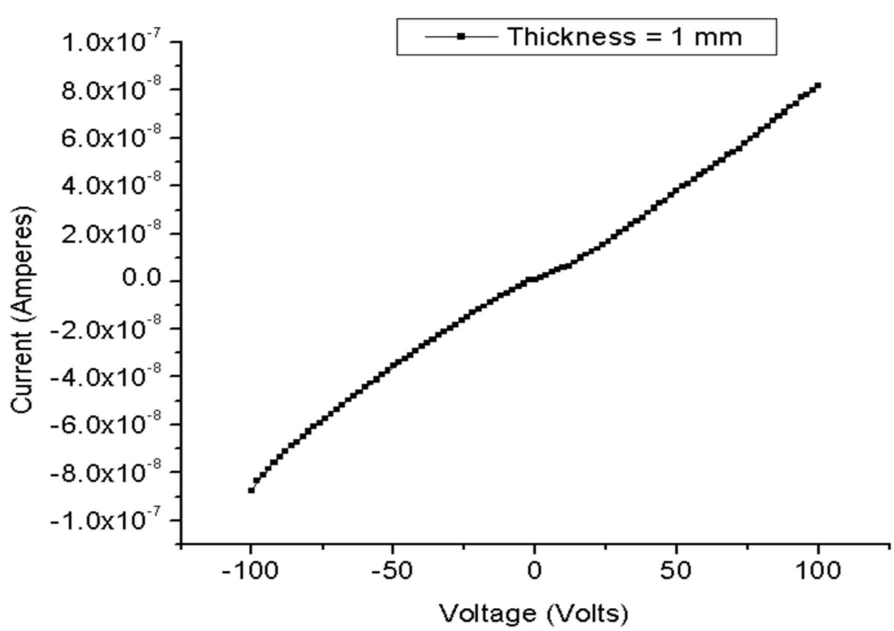

Fig. 13 : Current versus Voltage Characteristics of the Diamond detector of 1 mm thickness

VI. Conclusions

First prototypes of single crystal Diamond based Alpha detectors have been successfully fabricated at IIT-Bombay. Technology for fabrication of diamond detectors has been developed at IIT-Bombay. Physics based simulations in TCAD proved helpful in understanding the charge transport mechanism within the bulk of the diamond detector. Device simulations yielded a bulk resistance of 1.33 GΩ and also confirmed Ohmic response of the detector. Dynamic simulations incorporating alpha particle incidence played a crucial role in studying the charge generation mechanism within the diamond crystal. Dc characterization of diamond detectors yielded a terminal dc current value of 82 nA at 100V implying a bulk resistance of 1.30 GΩ.

Analytical values of dc performance parameters derived from TCAD simulations were found to be having a deviation <5% from those achieved by characterization. Exhaustive dynamic characterization studies on Diamond detectors employing radiation sources (^{241}Am) are to be taken up shortly.

VII. Acknowledgments

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Evolution and Efficiencies of Energy Metering Technologies in Ghana

By Emmanuel Effah & Kingsley Bediako Owusu
University of Mines and Technology, Ghana

Abstract- This paper examined the efficiencies of the evolved energy metering technologies used by the Electricity Company of Ghana (ECG) vis-à-vis their metering challenge. We used literature survey and field interactions with ECG experts and electricity consumers in Ghana in order to firmly conclude. This paper determined that the types of Post-paid and Prepaid metering technologies employed so far never addressed ECG's metering challenge. The Prepaid metering technology, being the latest, was found to be more porous to energy theft and fraud or illegal connections than even the traditional post-paid technology. The economic conditions of energy consumers, their corrupted instincts, the "customer factor"/tamper possibility of meters, the technical know-how of the flaws in installed metering technology and sometimes instigations from technical experts propelled consumers to take advantage of the technological porosity to manipulate the metering system to their advantage. Advanced Metering Technology (AMT) whose billing system runs parallel with mobile phone billing system, without the "customer factor", was recommended to address ECG's metering challenges.

Keywords: electricity company of ghana, energy meters, illegal connections, electromechanical induction meters, advanced metering technology.

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I. Introduction

Technological advancements in the 21st century offer us unprecedented opportunities to solve our present problems and those of the generations to come. Technology in Ghana's Energy Sector has seen a lot of evolutions in the recent past especially in the area of metering and tariff estimation. The prime aim of these technological advancements and evolutions at a specific time in a given environment is to provide the best solutions to our problems. A given technology might best solve a problem in one environment and fail in another due to the prevailing factors governing the selection, the technical know-how of those placed in charge of the technology and how the implementation or installation of the technology is carried out.

The proven obstacles to efficient power generation, transmission and distribution are losses but can be minimized if properly managed [1]. Losses are any input energy that goes unbilled or unmetered [2]. But it is known that a larger percentage of the losses are non-technical, which emanate from the consumers' end [3]. Among the common factors responsible for non-technical losses are: energy pilferages and thefts, defective meters generating errors in meter readings, wrongful estimation of meter readings, un-metered or flat rated consumers, customers tampering with their meters, free power usage (for legally connected consumers), illegal connections, etc. [4]. These Non-technical losses (NTL) account for over 70% of the total losses representing several hundreds of kilo Volts Amperes.

Critical considerations of all the NTLs sum up to metering losses. The reason is that Power Suppliers cannot remotely and effectively monitor the happenings at the consumers' end and take the necessary action efficiently. Consequently, the Electricity Company of Ghana (ECG) has deployed a number of metering technologies to address this problem. These included: Electromechanical Induction Meters (EIM) or Standard Meters, Prepayment Card Electric Meters, Solid State Electric Meters or Electronic Meters and presently, Pole Prepaid Card Meters. This paper examined the different metering technologies adopted by ECG, why they excelled or failed and recommend better alternatives.

Electricity distribution is a sector where technological evolution is gradual, at least in the network assets. However, there is a field, in which progress in the last few years has been rapid, at a speed typical of the telecommunications sector. The present goal is towards Remote metering, reading, and monitoring of electricity consumption referred to as advanced metering infrastructure (AMI) [5]. Drasticreductions in prices of metering and telecommunication equipment is making their adoptioneconomically feasible, starting with large consumers and gradually applying AMI to medium andsmall ones.

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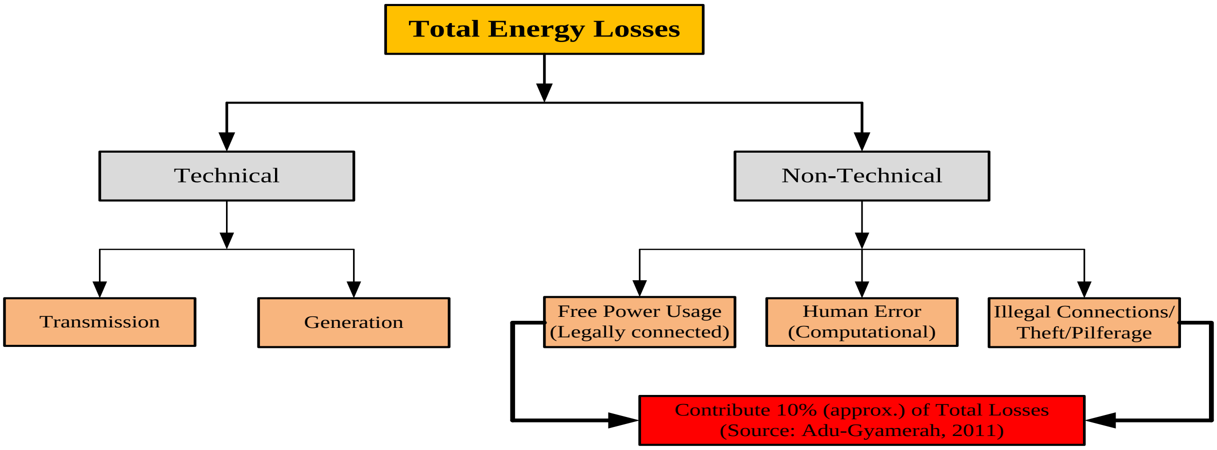

Figure 1 : Classification of Energy Losses [6]

II. The Big Problem

The most predominant objectives of energy meters are to increase operational efficiency; to enhance durability of energy grids; and to reduce operational cost [7]. As confirmed, every energy meter should be able to at least help in the elimination of fraud and theft (possibility of tampering with meter), reductions in meter reading costs, reduction in prepayment metering costs and reductions in peak demand (thus, reductions in energy usage during peak demand), automatic adjustments of rate with respect to subsidies per energy usage – lower costs, better security of supply and efficient billing [8]. Also, lack of consumer information in conventional metering may be a barrier to reducing energy consumption (reducing energy wastage). This is because energy-use related information could be used to help consumers make decisions relating to energy use and the choice of appliances to minimize energy wastages. The predominant electromechanical metering system lack this feedback functionality and hence deprives consumers the desired awareness about energy efficiency and a better understanding of the energy consumption experience, budgeting and planning benefits.

The greatest challenge of energy distribution by ECG has ever been free power usages; and this constitutes over 70% of their total losses [6]. Factually, several factors encourage this challenge, but in all cases the solution seems imbued in the installed metering technology. With the recent metering technologies (prepaid card metering technologies) in the urban centres, energy consumers are conscious of the fact that the energy meter could be by-passed. No wonder ECG was unable to bill over 100,000 customers connected to the national grid in 2013 [9]. Again, 9,537 illegal electricity connections (by-passing the prepayment meters) were detected, constituting GH¢ 18.23 million (US$9.115 million) loss of revenue to the nation [6]. The big problem is as a result of the Tamper-Possibility of installed energy metering system without any efficient monitoring mechanisms, thus the existence of "consumer and or Energy Provider factor" in the tariff estimation chain. If the possibility of manipulating the system exists, then the poor consumer will definitely be tempted to also take advantage after all, as many people are doing it. ECG therefore needs metering system with the effectiveness to detect and discourage theft and other ways of enormous unmetered consumption. This is because deploying the right metering technology significantly contributes to sustainable development and efficient performance of the power sector in developing countries, for the reason that it provides powerful tools to reduce total losses and increase collection rates. After all, the rural folks are even capable of paying their electricity bills without any external interventions [10].

Considering the behavioral trends, the economic discrepancies/hardships and geographical distributions of ECG's consumers, the most efficient and desired metering technology of greatest want in Ghana should have the following catalogued qualities:

a) *"Watchdog" effect on Consumers*

Consumers being aware that ECG continuously and actively monitors Electrical power consumption at their convenience can quickly detect any abnormal consumption due to tampering or by-passing of a meter and take fast corrective action to ensure consumer discipline. This has been shown to be extremely effective with all categories of large and medium consumers having a history of stealing electricity. They stop stealing once they become aware that the utility has the means to detect and record it. Recent experience in such countries as the Dominican Republic and Honduras shows that consumers stop stealing if they face the risk of social condemnation [11]. These measures can significantly increase the revenues of ECG and eliminate their outrageous non-technical losses.

Global Journal of Researches in Engineering (F) Volume XIV Issue VI Version I Year 2014

b) Enhancement of the company's corporate governance and anti-corruption efforts

Instances of theft by large consumers usually involve collusion between these consumers and meter readers. Most consumers acquired the needed expertise of by-pass meters, "jeossing" or minimizing the monthly readings of meters, etc. from field service personnel. Corruption is also likely to occur in operations of service disconnection related to unpaid bills and other free power consumers. Installing the right metering technology eliminates those field operations (meter reading and service disconnection, tampering with the accuracies of meters, flat rating operations) and makes information on consumption transparently available to the consumers and managers of ECG. This will greatly enhance governance and reduce corruption.

c) Implementation of pre-paid consumption

Pre-paid consumption is generally a very good commercial choice for low-income consumers. There are dozens of cases of very poor countries in Africa, Asia, and Latin America with a booming mobile phone industry, often by-passing land lines. According to the International Telecommunication Union, by the end-2007, about 60 percent of mobile subscriptions in the whole world were prepaid. The Prepayment system stimulates users' consciousness regarding power consumption [10]. Although prepaid tariffs tend to be more expensive (per minute) than postpaid tariffs, the prepaid mobile subscriptions in Ghana exceed 60 percent [10]. It is the most practical payment option available to low-income users who might not have regular income.

With this quality, it is expected that Credit bought by the consumer is loaded in his/her account in a commercial management system (CMS) with the aid of mobile phones or similar devices. The customer should be able to access his remaining credit, receive alert messages from ECG when the credit is about to expire, buy new credit, received disconnection message, etc. Remote disconnection and reconnection should be possible even for low-voltage consumers in cases of credit expiration and non-renewal in the same way pre-paid mobile phones work.

This approach of pre-paid consumption must show significant improvement over the classic pre-paid card meters widely used in South Africa and other countries. The principal ones must include: significantly lower hardware costs, and permanent monitoring of consumption, which is not possible with the classic card meter [11].

III. Types of Metering Technologies Adopted so far

The present power sector arrays three agents- Volta River Authority (VRA)-in-charge of power Generation, Ghana Grid Company (GridCo) – responsible for bulk power transmissions and lastly, ECG distribute or sell power to consumers. ECG distribute/sell power to three core consumers viz: industrial, commercial and residential customers. Though VRA and GRIDCo deploy meters in their operations, this paper however deals with the case of ECG because of their higher non-technical losses or "metering losses". ECG has always relied on the services of different energy metering technologies to bill their stated customers. Meters are devices installed in the Customers' premises to measure and record the amount of electricity supplied (consumed) over a period of time. Presently, there are two (2) kinds of meters installed in customers' premises: the post - paid and pre – paid meters or Smart Cash (as usually called in Ghana).

ECG predominantly use Ferraris meters; some of them have maximum demand indication whilst others do not have. Digital meters have been introduced recently in both transmission (by GRID Co) and distribution networks (by ECG). Meters with Time-of-used functionalities are not in use but there has been introduction of prepaid meters by ECG. In the distribution network, residential and commercial customers are billed by the energy (kilo-Watt-hour or kWh) consumed. There are however some customers without meters who are billed on "estimated energy consumed" (Flat Rate). The flat rated consumers pay fixed amounts every month irrespective of the amount of electrical energy (kWh) consumed.

a) Post-Paid metering technology

The aged-electromechanical induction watt-hour meters and the recent digital or electronic meters are the main post-paid meters prevalent in Ghana.

i. *Electromechanical Induction Meters (EIM)*

These meters operate by counting the revolutions of a non-magnetic, but electrically conductive, metal discs which are made to rotate at a speed proportional to the power passing through the meters. The number of revolutions is thus proportional to the energy (kWh) consumed. The disc is acted upon by two sets of coils, which in effect form two phase induction motor. One coil is connected in such a way that it produces a magnetic flux in proportion to the voltage and the other produces a magnetic flux in proportion to the current. The field of the voltage coil is delayed by 90 degrees, due to the coil's inductive nature, and calibrated using a lag coil. This produces eddy currents in the disc and the effect is such that a force is exerted on the disc in proportion to the product of the instantaneous current, voltage and phase angle (power factor) between them. A permanent magnet exerts an opposing force proportional to the speed of rotation of the disc. The equilibrium between these two opposing forces results in the disc rotating at a speed proportional to the power or rate of energy usage. The disc drives a register mechanism which counts revolutions in order to render measurement of the total energy used. This type of meter is used on a single-phase AC supply. Multi-phase (2 or 3-Phase) configurations will require additional voltage and current coils. Figure 2a presents a typical EIM used in Ghana.

ii. *Electronic Meters*

These energy meters 'operation is similar to the electromechanical induction type, in that the energy used is digitally displayed on an LCD or LED screen, and some (not used in Ghana) can also transmit readings to remote places.

These meters, sometimes called Solid State Electric Meters (SSEM), have digital signal processing "engine" that codes/processes digital signals received from analogue to digital converters into information that can be analysed. In addition to measuring energy used, some electronic meters can also record other parameters of the load and supply such as instantaneous and maximum rate of usage demands, voltages, power factor and reactive power used, etc. They can also support time-of-day billing, for example, recording the amount of energy used during on-peak and off-peak hours. They calculate and show the exact value of the electricity consumed rather than its amount. The rate of the unit consumed varies according to the time of the day and the day of the week.

As illustrated in Figure 2(b), these electricity meters must be manually read every month by representatives of ECG for the bills to be estimated hence the name Post-Paid Meters.

Figure 2 : Post-Paid Meters (a) EIM Type (b) Electronic Type

b) *Pre-Paid/Smart Cash (as called in Ghana) or Prepayment Electric Metering Technology*

Generally, prepayment electricity meters in Ghana measure energy in the same manner as a conventional EIM. The main difference with a prepayment meter lies in the intended manner in which the meter is to be operated and used for the sale of electricity. The prepayment electric meters accept tokens or prepaid cards to get electricity supply. The customer has to pay the charges for the power supply in advance. One can also top-up the amount for extending the period of electric supply or when the balance over the supply is automatically cut off by a relay in the electric meter. Thus, electricity consumption is integrally measured but the measurement is actually started and stopped in conjunction with the activation and deactivation of the load circuit by the prepayment control system. To activate the load circuit, the consumer must prepay for electricity usage or purchase a quantity of electricity that may include statutory or fixed charges. The payment information may be loaded on the meter through a specific peripheral control device like the magnetic card reader used by ECG. Once activated, the load circuit will run and remain activated until the monetary or equivalent energy information loaded into the prepayment control system has run out, subject to any other conditions established by the contractor.

The consumer can buy electricity through various vending options as token with a code printed on it. The meter is credited with the amount of credit bought and supply is switched on automatically at the load side. As the consumer's balance reaches the emergency limit or "grace period" corresponding to a set value by ECG, the meter signals for recharge. If the "grace period" expires then the meter automatically disconnects the supply at load side.

As shown in Figure 3 (a), the commonest type of prepaid meters installed in Ghana is the traditional EIMs with the system to engage and disengage supply to the load side. Virtually, this meter has nothing to aid monitoring power theft, fraud or illegalities facing ECG.

i. *Pole Prepaid Meters*

The prepaid meters replaced some postpaid meters in Ghana in the year 2005 up to date. According to ECG, the prepaid meters will ensure efficiency in the usage of electricity and also reduce the cumbersome work of ECG personnel in the processes of billing. Thus, the prepaid meters are indeed convenient to ECG and the personnel because there is no need for distribution of electricity bills to various houses or residence. In fact, ECG until not many years ago, were sending their personnel to residential and non-residential premises to read credit meters and also deliver bills. They then switched partly to Pre-paid meters installed in both residential and non-residential premises.

In spite of the fact that they have not finished changing all the traditional EIMs to Pre-Paid ones, it is speculated that they will introduce 'Smart Pre-Paid Meters' in 2014. Surprisingly, they are replacing existing pre-paid card meters or the smart cash meters to 'Pole prepaid card meters' which leaves customers to various risks. This is because consumers 'lives and properties are posed with danger with the "pole metering system", especially when consumers leave their secured house to poles on the street to reload credit to the pre-paid meter. Now the big question still holds "do these pole meters address our metering challenges?"

Figure 3 : Prepaid Meters (a) Home Type (b) Pole Types

IV. Critical Issues

Several metering technologies have evolved but the question is "how these technologies efficiently addressed the stipulated metering challenges in Ghana's energy sector". Do we just adopt the technology because it is successfully used elsewhere or we need to do retrospection to discover what we actually need? The inception of the pre-paid meters has rather increase illegal connections in the energy sector instead of curbing the menace. Also, countless consumers on the post-paid metering system are either unmetered at all or improperly billed [10]. The tamper possibilities and the hassles in billing render the post-paid meters unsuitable. The prepaid meters are convenient to ECG and their personnel because they have jettisoned the hassles in the distribution of electricity bills to various customers. Perusing this freely expressed merit of the installed prepaid meters with a typical Ghanaian eye, not with an assumed eye of perfection of most Ghanaians, one can say the post-paid meters are arguably more efficient. The old system of post payment saw to the problem of various illegal connections and free power usages with the meter wiring. Over 70% of ECG's debt has been attributed to illegal connections and free power usages [9]. If the post-paid system where there were monthly or routine visits by ECG personnel to various compounds to distribute electricity bills saw various illegal connections or free power usages, audience can guess what is happening with the present non-tamper evident pre-paid metering system. In 2013, 9,537 illegal electricity connections (by-passing the prepayment meters) were detected, constituting a GH¢ 18.23 million (US$9.115 million) loss [6]. All these illegalities were found with customers on the prepaid meters.

So the question to answer is that "are we dealing with an enjoyable era of convenience? Or we are planning to launch a new debt recovery scheme for the ECG again".

V. Proposed Technology

Several authors have racked brains for the best electricity metering technology but the ideal solution has not been found. Quite a lot of countries have and are still benefitting from the "outdated" electromechanical metering technology. However, this technology is aproxy of free power usages and complementary source of illegalities in Ghana's energy sector. The "customer factor" in our electricity billing is the main albatross around the neck of ECG's metering system. Figure 4 shows the causes of metering losses, and mitigating these causes imply addressing the non-technical losses in the energy sector.

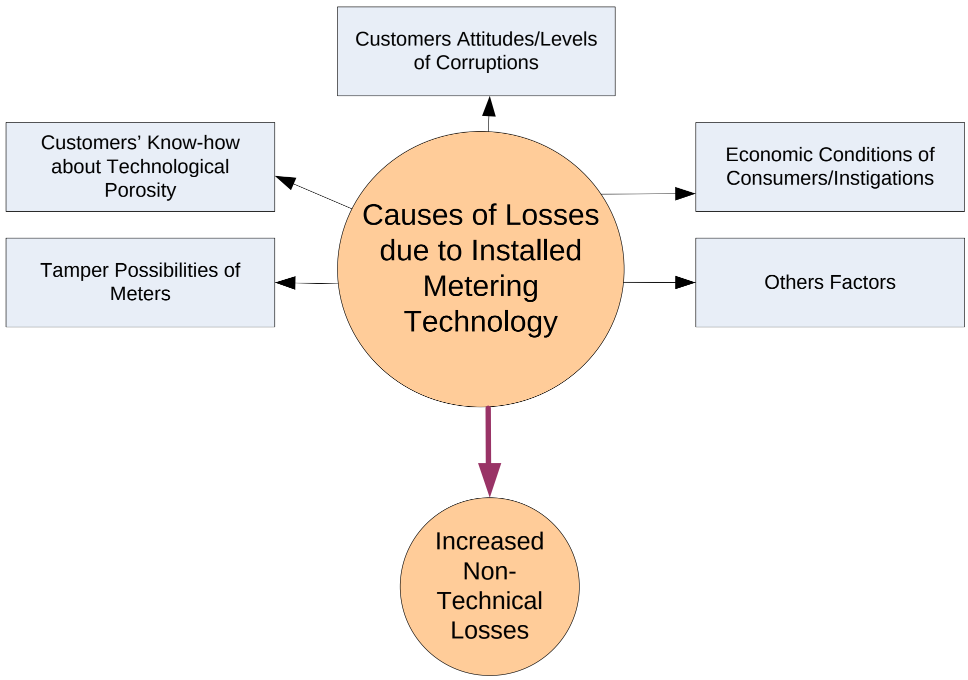

Figure 4 : Causes of Metering Losses in Ghana

With the cemented facts about the deployed metering technologies so far, customized Advanced Metering Technology (AMT) commonly known as a 'smart metering Technology (SMT)' is recommended for ECG. The Economic conditions of energy consumers, their corrupted instincts, the "customer factor"/tamper possibility of meters, the technical know-how of the flaws in the installed metering technology and sometimes instigations from technical experts propel consumers to take advantage of the technological porosity to manipulate the metering system to their advantage. AMT whose billing system runs parallel with mobile phone billing system is a remedy.

AMT is a reasoning instrument with enhanced intelligence. When it is applied to the measurement of a specific resource, such as electricity, and networked with similar mechanisms within a domestic context, its value and potential become clear [12].

AMT employs two-way communication, which allows a household meter to communicate with the suppliers' information systems, and vice versa, and allows remote control mechanisms but only from the suppliers' end. Interval reading functionality is one of the most important components of AMT systems as it allows the autonomous retrieval, storage and communication of consumption data according to time-of-use.

An advanced metering system (AMS) is an electronic metering device at the point of consumption, along with the communicative potential for metered data to be transmitted and processed for meaningful action or feedback. This creates an environment where information must be either sent by unconventional means outside the premises, or communicated directly to the occupants, via a feedback channel. The later allows users (or occupants of the building) to understand and manage the associated resources with minimal or no external support.

VI. Conclusion

Technology has come far to solve our problems when rightly applied. Thus, a particular technology might be a success at one place and a failure at a different place. Several energy metering technologies have evolved in Ghana but none seemed to address the metering challenges of ECG. The latest technologies are rather more problematic than the traditional ones. The Economic conditions of energy consumers, their corrupted instincts, the "customer factor"/tamper possibility of meters, the technical know-how of the flaws in the installed metering technology and sometimes instigations from technical experts propel consumers to take advantage of the technological porosity to manipulate the metering system to their advantage.

AMT whose billing system runs parallel with mobile phone billing system, without the "customer factor", is recommended to address ECG's metering challenges.

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Enhancement of Transient Stability in a Deregulated Power System using Facts Devices

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Abstract- In a deregulated power system, the electric power demand is increasing day to day which may lead to overloads and loss of generation. Transient stability studies place an important role in power systems, which provide information related to the capability of a power system to remain in synchronism during major disturbances resulting from either the loss of generation or transmission facilities, sudden or sustained load changes. The analysis of transient stability is very important to operate the power system more secure and this paper focuses on increasing the transient stability [1] using FACTS devices like TCSC (Thyristor Controlled Series Capacitor), TCPAR (Thyristor Controlled Phase Angle Regulator), SVC (Static Var Compensator). These FACTS devices are optimally placed on transmission system using Sensitivity approach method. The proposed method is to enhance the transient stability on Modified IEEE-14 bus system and IEEE-24 bus system Using Power World Simulator 17 software.

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GJRE-F Classification : FOR Code: 090607

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Strictly as per the compliance and regulations of :

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J. Srinivasa Rao α & J. Amarnath σ

Abstract- In a deregulated power system, the electric power demand is increasing day to day which may lead to overloads and loss of generation. Transient stability studies place an important role in power systems, which provide information related to the capability of a power system to remain in synchronism during major disturbances resulting from either the loss of generation or transmission facilities, sudden or sustained load changes. The analysis of transient stability is very important to operate the power system more secure and this paper focuses on increasing the transient stability [1] using FACTS devices like TCSC (Thyristor Controlled Series Capacitor), TCPAR (Thyristor Controlled Phase Angle Regulator), SVC (Static Var Compensator). These FACTS devices are optimally placed on transmission system using Sensitivity approach method. The proposed method is to enhance the transient stability on Modified IEEE-14 bus system and IEEE-24 bus system Using Power World Simulator 17 software.

Keywords: deregulated power system, ATC, TCSC, TCPAR, SVC.

I. Introduction

In a deregulated power system structure, customers share a common transmission network for wheeling power from the point of generation to the point of consumption. All parties in this open access environment may try to produce the energy from the cheaper source for greater profit margin. It may lead to overload of the power system. This may result in violation of stability limits and thereby undermine the system security. Transient stability of a system refers to the stability when subjected to large disturbances such as faults and switching of lines. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power angle relationship.

Transient stability [2] studies place an important role in power systems, which provide information related to the capability of a power system to remain in synchronism during major disturbances resulting from either the loss of generation or transmission facilities, sudden or sustained load changes, in the voltages, currents, powers, speeds and torques of the machines of the power systems as explained.

FACTS devices are capable of controlling the network condition in a very fast manner and this unique feature of FACTS devices can be exploited to enlarge the decelerating area and hence improving the first swing stability limit of a system. Due to FACTS device placement in the main power transfer path of the critical machine, the output power of the machine and hence its first swing stability limit can be increased by operating the FACTS device at its full capacitive rating. Control strategy was proposed based upon local input signals can be used for series and shunt compensator devices to damp power swings. Using the proposed control strategies [8], the series and shunt connected compensators can be located in several locations.

Flexible AC Transmission Systems (FACTS), provide proven technical solutions to address these new operating challenges being presented today. Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angle Regulator (TCPAR) and Static VAR Compensator (SVC) are used for enhancement of Transient Stability using Sensitivity based methods.

II. Structure of Regulated and Deregulated Systems

The former vertically integrated utility, which perform all the functions involved in power,(i.e., generation, transmission, distribution and retail sales) known as regulated system, is dis-aggregated in to separate companies devoted to their functions called as Deregulated system.

The main aim of restructuring [6] the power market is as follows:

- To secure that all reasonable demands for the electricity are met.
- Promote competition in the generation and supply of electricity.
- Protect the interests of electricity customers in respect to prices charged, continuity of supply and the quality of services provided.
- Promote efficiency and economy on the part of licensees in supplying and transmitting electricity.

The following figure-1 shows the typical structure of regulated power system which is simply vertically integrated where the cash flow is uni-directional from consumers to electric utility.

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Figure 1 : Typical Structure of Regulated Electricity System

For developing countries, the main issues have been a high demand growth coupled with inefficient system management and irrational tariff policies. This has affected the availability of financial resources to support investments in improving generation and transmission capacities.

The goal of changing the way of operation, i.e., re-regulation or de-regulation, as we say, is to enhance competition and bring consumers new choices and economic benefits.

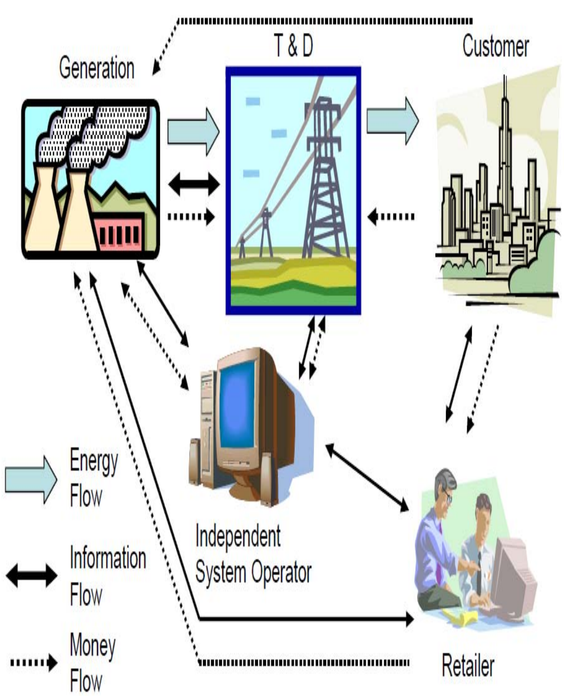

Figure 2 : Typical Structure of Deregulated Electricity System

In a deregulated system a system operator is appointed for the whole system and it is entrusted with the responsibility of keeping the system in balance, i.e. to ensure that the production and imports continuously match consumption and exports. Different power sellers will deliver their product to the customers (via retailers), over a common set of T and D wires, operated by the independent system operator (ISO). The generators, T and D utility and retailers communicate with the ISO.

III. Facts Controllers

a) Thyristor Controlled Series Compensator (TCSC)

Thyristor Controlled Series Capacitor (TCSC) is a capacitive reactance compensator which consists of a series of capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance.

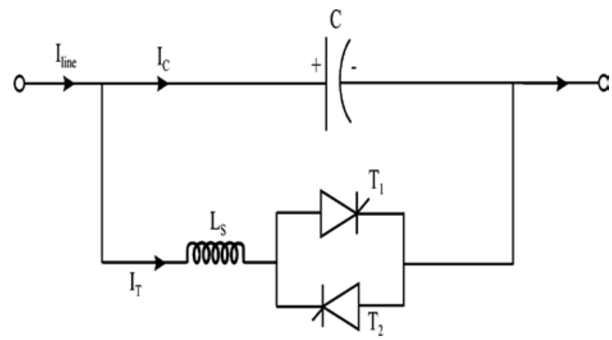

Figure 3 : Thyristor Controlled Series Capacitor

The impedance characteristics of TCSC shows, both capacitive and inductive region are possible though varying firing angle (α).

- 90 < α < αLlim Inductive region
- αClim < α <180 Capacitive region
- αLlim< α < αClim Resonance region

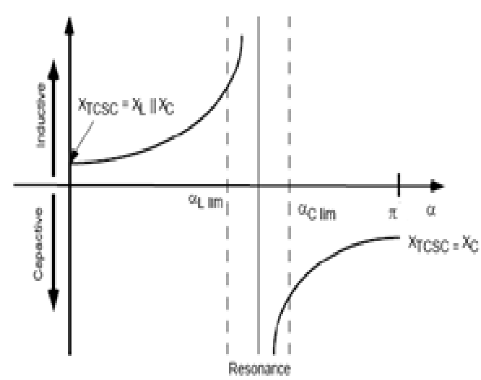

Figure 4 : Variation of impedance in case of TCSC

i. *Static Modelling*

The Figure shows a simple transmission line represented by its lumped pi equivalent parameters connected between bus-i and bus-j. Let complex voltage at bus-i and bus-j are Vi < δi and Vj < δj respectively. The real and reactive power flow from bus-i to bus j can be written as [5] :

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$$P_{ij} = V_1^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] \quad (3.1)$$

$$Q_{ij} = -V_i^2(B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})] \quad (3.2)$$

Where δij = δi-δj, similarly the real and reactive power flow from bus-j to bus-i is;

$$P_{ji} = V_1^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] \quad (3.3)$$

$$Qj_{ji} = -V_i^2(B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})] \quad (3.4)$$

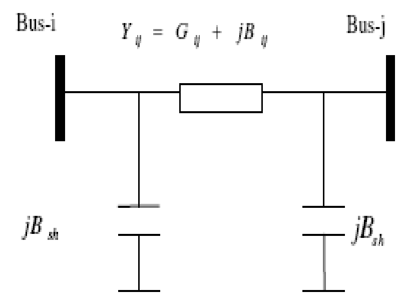

Figure 5 : Model of Transmission line

The model of transmission line with a TCSC connected between bus-i and bus-j is shown in Fig. During the steady state the TCSC can be considered as a static reactance -jXc. The real and reactive power flow from bus-i to bus-j, and from bus-j to bus-i of a line having series impedance and a series reactance are,

$$P_{ij}^C = V_i^2 G_{ij}' - V_i V_j (G_{ij}' \cos\delta_{ij} + B_{ij}' \sin\delta_{ij}) \quad (3.5)$$

$$Q_{ij}^C = -V_i^2 (B_{ij}' + B_{sh)} V_i V_j (G_{ij}' \sin\delta_{ij} - B_{ij}' \cos\delta_{ij}) \quad (3.6)$$

$$P_{ji}^c = V_j^2 G_{ij}' - V_i V_j (G_{ij}' \cos\delta_{ij} - B_{ij}' \sin\delta_{ij}) \quad (3.7)$$

$$Q_{ji}^c = -V_j^2 (B_{ij}' + B_{sh}) + V_i V_j (G_{ij}' \sin\delta_{ij} + B_{ij}' \cos\delta_{ij}) \quad (3.8)$$

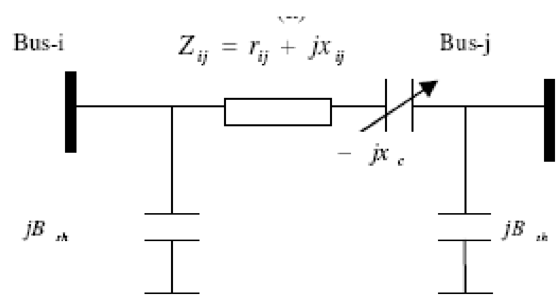

Figure 6 : Model of Transmission line with TCSC

The active and reactive power loss in the line having TCSC can be written as, from equations 3.5, 3.7 & 3.6, 3.8.

$$P_L = P_{ij}^c + P_{ji}^c = G_{ij}'(V_i^2 + V_j^2) - 2V_i V_j G_{ij}' \cos\delta_{ij} \quad Q_L = Q_{ij}^c + Q_{ji}^c = -(V_i^2 + V_j^2)(B_{ij}' + B_{sh}) + 2V_i V_j B_{ij}' \cos\delta_{ij}$$

Where, $G_{ij}' = \frac{r_{ij}}{(r_{ij}^2 + (x_{ij} - x_c)^2}$

$$B_{ij}' = -\frac{-(x_{ij} - x_c)}{r_{ij}^2 + (x_{ij} - x_c)^2}$$

The change in the line flow due to series capacitance can be represented as a line without series capacitance with power injected at the receiving and sending ends of the line as shown in Figure.

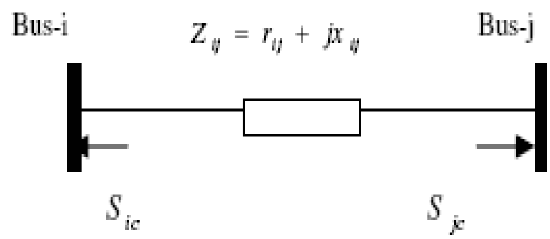

Figure 7 : Injection Model of TCSC

The real and reactive power injections at bus-i and bus-j can be expressed as,

$$P_{ic} = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} cos\delta_{ij} + \Delta B_{ij} sin\delta_{ij}] \quad (3.9)$$

$$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} cos\delta_{ij} - \Delta B_{ij} sin\delta_{ij}] \quad (3.10)$$

$$Q_{ic} = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij} sin\delta_{ij} + \Delta B_{ij} cos\delta_{ij}] \quad (3.11)$$

$$Q_{jc} = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij} sin\delta_{ij} - \Delta B_{ij} cos\delta_{ij}] \quad (3.12)$$

$$\Delta G_{ij} = \frac{x_c r_{ij} (x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)2)}$$

$$\Delta B_{ij} = \frac{-x_c (r_{ij}^2 - x_{ij}^2 + x_c x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)2)}$$

This Model of TCSC is used to properly modify the parameters of transmission line with TCSC for optimal location.

ii. *Thyristor Controlled Phase Angle Regulator (Tcpar)*

Thyristor Controlled Phase Angle Regulator 'TCPAR' for power flow studies and the role of that modeling in the study of Flexible Alternating Current Transmission Systems 'FACTS' for power flow control are discussed. In order to investigate the impact of TCPAR on power systems effectively, it is essential to formulate a correct and appropriate model for it. The TCPAR, thus, makes it possible to increase or decrease the power forwarded in the line where it is inserted in a considerable way, which makes of it an ideal tool for this kind of use. Knowing that the TCPAR does not inject any active power, it offers a good solution with a less consumption.

a. Static Modelling of Tcpar

It is modeled by a voltage source, which represents the branch series, and of a power source representing the branch shunt. In computing the power flow, these devices are modeled using an ideal transformer with complex transformation ratio μ.

In the case of the TCPAR [5], the transformation ratio is expressed as:

$$\bar{\mu} = e^{j\theta} \quad (3.13)$$

Thus, it only affects the voltage angle while its magnitude remains constant.

For a TCPAR introduced into a transmission line as shown in the figure, a voltage *VTr* is introduced and it is expressed as a fraction of the voltage *Vm* at the bus m to which it is connected. It can be written as:

$$\overline{V_t} = \overline{V_m} + \overline{V_{Tr}} \quad (3.14)$$

And as,

$$\overline{V_m} = \overline{V_t}\,\bar{\mu} \quad (3.15)$$

Then,

$$\overline{V_{Tr}} = \overline{V_m} - \frac{\overline{V_m}}{\bar{\mu}}$$

Or

$$\overline{V_{Tr}} = \overline{V_m}(\bar{\mu} - 1/\bar{\mu}) \quad (3.16)$$

For a TCPAR introduced at the bus m of a transmission line as shown in figure 8., the equation which defines the relationship between the currents injected into the line and the voltages at buses *t* and *k* is:

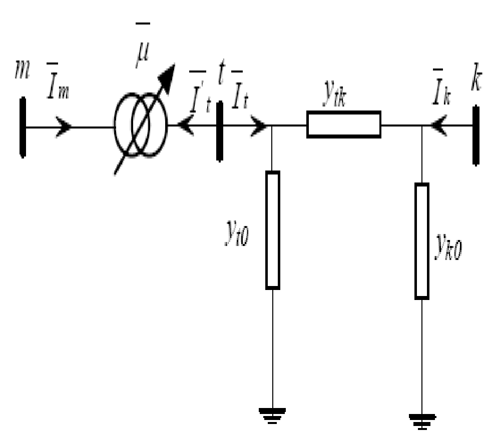

Figure 8 : model of transmission line with TCPAR

$$\overline{I}_t^{'} = Y_{tt}\overline{V_t} + Y_{tk}\overline{V_k} \quad (3.17)$$

$$\overline{I}_K = Y_{Kt}\overline{V}_t + Y_{KK}\overline{V}_K \quad (3.18)$$

Such as,

$$Y_{tt} = Y_{tK} + Y_{t0} \quad (3.19)$$

$$Y_{KK} = Y_{tK} + Y_{K0} \quad (3.20)$$

$$Y_{tK} = Y_{Kt} = -Y_{tK} \quad (3.21)$$

Knowing That,

$$\overline{I}_t^{'} = \overline{I}m\overline{\mu}^* \quad (3.22)$$

Considering above equations, the new expressions of the currents become:

$$\overline{I}m = \frac{Y_{tt}}{\overline{\mu}^*}\overline{V}m + \frac{Y_{tt}}{\overline{\mu}^*}\overline{V}_{Tr} + \frac{Y_{tK}}{\overline{\mu}^*}\overline{V}_K$$

$$\overline{I}_K = \frac{Y_{Kt}}{\overline{\mu}^*}\overline{V}_m + Y_{KK}\overline{V}_K$$

The admittance matrix of the new line has the form:

$$\begin{bmatrix}\overline{I}m\\ \overline{I}_K\end{bmatrix} = [Y]\begin{bmatrix}\overline{V}m\\ \overline{V}_{Tr}\\ \overline{V}_K\end{bmatrix}$$

b) Static Var Compensators (Svc)

A common practice of system voltage adjustment is shunt reactive power compensation. The synchronous condenser was historically an important tool of shunt reactive power compensation. Since it is a rotating machine, its operation and maintenance are quite complicated. New synchronous condensers are now seldom installed. The static shunt reactive power compensation, as opposed to the rotating synchronous condenser, has wide industrial application due to its low cost and simple operation and maintenance.

Conventional static shunt reactive power compensation is to install capacitors, reactors, or their combination, at the compensated buses to inject or extract reactive power from the system. Mechanical switches are used to put the shunt capacitor/reactors into or out of operation.

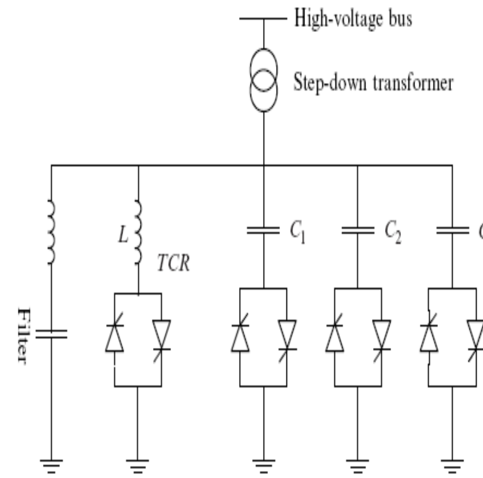

Figure 9 : SVC basic diagram

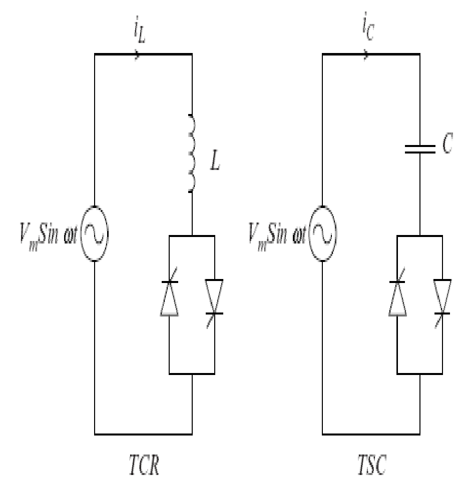

Figure 10 : TCR and TSC branches

Apparently the inductor current is zero when the two valves are off. When the valve conducts, neglecting the resistance in the reactor, the inductor current is

$$L\frac{di_L}{dt} = V_m sin\omega t \quad (3.23)$$

Where L is the inductance of the reactor, Vm is the magnitude of the system voltage.

Its general solution is

$$i_L = K - \frac{V_m}{\omega L}cos\omega t \quad (3.24)$$

Where K is the integral constant. Since the inductor current is zero at firing, the above equation yields

$$i_L = K - \frac{V_m}{\omega L}\cos(\alpha + K\pi) = 0 \quad (3.25)$$

Substituting the solution of K in to equation 3.25 gives rise to the inductor current.

$$i_L = \frac{V_m}{\omega L}[cos(\alpha + K\pi) - cos\omega t] \quad K = 0,1,2, \dots ....$$

Based on the above equation, inductor current returns to zero at

$$\omega t = (K+2)\pi - \alpha$$

Thus the valve conducting period is

$$\omega t \; \epsilon \; [K\pi + \alpha, (K+2)\pi - \alpha] \;\; K = 1,2,3, \ldots.$$

The adjustment of firing angles changes the current peak values and conducting periods. Applying Fourier analysis to the current yields the magnitude of the fundamental frequency Component.

$$I_{L1} = \frac{2}{\pi}\int_{\alpha}^{2\pi-\alpha} \frac{V_m}{\omega L}(cos\alpha - cos\theta)\cos\theta \, d\theta = \frac{V_m}{\pi\omega L}[2(\alpha - \pi) - sin2\alpha] \qquad (3.26)$$

And the instantaneous value of fundamental frequency component is

$$i_{L1} = I_{L1} cos\omega t = \frac{V_m}{\pi\omega L}(2\beta - sin2\beta) sin\left(\omega t - \frac{\pi}{2}\right) \qquad (3.27)$$

The equivalent fundamental frequency reactance of the TCR branch is

$$X_L(\beta) = \frac{\pi\omega L}{2\beta - sin\,2\beta} \beta \in [0, \tfrac{\pi}{2}]$$

Thus the TCR equivalent reactance of fundamental frequency components is the function of conducting angle β or the firing angle α. The control of firing angle α can smoothly adjust the equivalent shunt reactance. The reactive power consumed by TCR is

$$Q_L = \dot{V} i_{L1}^{*} = \frac{V^2}{X_L(\beta)} = \frac{2\beta - sin\,2\beta}{\pi\omega L} V^2 \qquad (3.28)$$

The TSC branch consists of a capacitor connected in series with two thyristors connected in parallel and in opposite directions. The TSC source voltage is the same as TCR. Its waveforms are in Figure. The TSC creates two operating states for the capacitors through valve control: shunt capacitors in service or out of service. Stopping the firing can simply put the capacitor out of service. Note that the natural switch-off from conduction happens when the capacitor current is zero and its voltage at the peak of source voltage. Neglecting the capacitor leakage current, capacitor voltage maintains the peak value if firing stops after the Natural switch-off. We need to pay attention to the timing of putting the capacitor into service.

The reactive power injection of the capacitors is

$$Q_C = \omega C V^2 \qquad (3.29)$$

Where C is the capacitance of the capacitor. From above two equations [3.28] & [3.29] we have the reactive power injection from the SVC is

$$Q_{SVC} = Q_C - Q_L = (\omega C - \frac{2\beta - sin\,2\beta}{\pi\omega L})V^2 \qquad (3.30)$$

The SVC reactive power injection can be smoothly adjusted when β€ [0,π/2]. To expand the regulation ranges of SVC, we can have many TSC branches in one SVC, based on the compensation requirements. Figure shows an SVC with three TSCs. When all three TSCs are in service, the C in above equation is C1+C2+C3. To guarantee a continuous adjustment, the TCR capacity should be slightly larger than a group of TSCs, that is, ωC1 < 1/ωL.

Based on above equation the equivalent reactance of SVC is

$$X_{SVC} = -\left(\omega C - \frac{2\beta - sin2\beta^{-1}}{\pi\omega L}\right) = \frac{\pi\omega L}{2\beta - sin2\beta - \pi\omega^2 LC}$$

In Figure, shown below there is a straight line going through the original corresponding to every β. The slope of the straight line is XSVC. Suppose that the system voltage characteristic is V1. The control scheme is to make the TCR conducting angle β1= π/2, corresponding to maximum equivalent inductive reactance. The SVC operating point is the crossover point A between system voltage characteristic V1 and the straight line β1. With system voltage characteristic V2 and TCR conduction angle β2 < β1, XSVC decreases and the SVC operating point shifts accordingly. Until system voltage characteristic is V6 and conduction angle β6= 0, SVC equivalent reactance is maximum capacitive with operating point B.

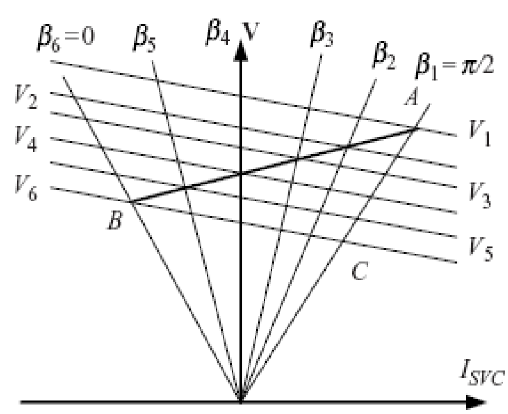

Figure 11 : Equivalent reactance variation with β as voltage changes

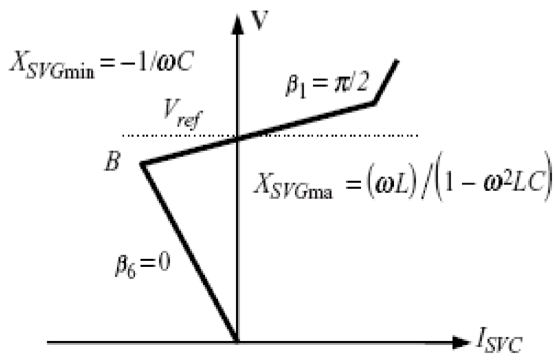

Figure 12 : Voltage–current characteristic

Apparently, voltage at B is higher than at C. When voltage changes between V1 and V6, the adjustment of b puts voltage under control. All the operating points constitute the straight line AB. The slope of AB and the crossover point with voltage axis Vref is determined by the control scheme of β. From voltage control point of view, the slope of AB is zero at best, without steady-state error. To maintain the control stability, SVC should have a small steady-state error and the slope of AB is around 0.05. Taking into consideration the steady-state control scheme, the SVC voltage–current characteristics are shown in Fig. voltage characteristics. When system voltage varies within the SVC control range, SVC can be seen as asynchronous condenser having source voltage of Vref and internal reactance of Xe.

$$V = V_{ref} + X_e I_{SVC}$$

Where Xe is the slope of the straight line AB in Voltage Characteristics, V and ISVC are the SVC terminal voltage and current. When system voltage is out of the SVC control range, SVC becomes a fixed reactor, XSVCmin or XSVCmax. SVC is considered as a variable shunt reactor in system stability and control analysis. SVC controller determines its admittance. We have introduced SVC basic principles. Special attention needs to be paid in industrial applications of SVC to capacity settings of reactors and capacitors, control strategy, flexibility of adjustments, protection, elimination of harmonics, etc .For example, in practical operation of an SVC, the range of the control angle is slightly less than [π/2, π] to make sure that valves can be triggered on and turned off securely.

IV. Optimal Location based on Sensitivity Approach for Tcsc, Tcpar and Svc

The static devices are considered in order to achieve the following in the power system:

1. Reduction in total system losses
2. Increased transfer capability
3. Reduction in total MVAR losses

a) Selection of optimal location of FACTS devices

Using loss sensitivity index, the FACTS devices are placed in a suitable location as follows:

The Reduction of Total System Reactive Power Losses Method sensitivity factors with respect to the parameters of TCSC , TCPAR and SVC are defined as:

- Loss sensitivity with respect to control parameter X_{ij} of TCSC placed between buses i and j,

$$a_{ij} = \frac{\partial QL}{\partial X_{ij}}$$

- Loss sensitivity with respect to control parameter X_{ij} and θ_{ij} of TCPAR placed at buses i and j

$$b_{ij} = \frac{\partial QL}{\partial \theta_{ij}}$$

- Loss sensitivity with respect to control parameter *Qi* of SVC placed at bus *i*,

$$C_i = \frac{\partial QL}{\partial Q_i}$$

These factors can be computed for a base case power flow solution. Consider a line connected between buses *i* and *j* and having a net series impedance of *Xij*. The loss sensitivities with respect to *Xij*, θ_{ij} and *Qi* can be computed as:

$$a_{ij} = \frac{\partial QL}{\partial X_{ij}}$$

$$= \left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right]\frac{R_{ij}^2 - X_{ij}^2}{(R_{ij}^2 + X_{ij}^2)^2} \quad (4.1)$$

$$b_{ij} = \frac{\partial QL}{\partial \theta_{ij}} = [-2V_iV_jB_{ij}\sin\theta_{ij}] \quad (4.2)$$

$$\text{and} \quad C_i = \frac{\partial QL}{\partial Q_i} = \frac{2V_j^2[\cos(2\alpha)-1]}{\pi X_l} \quad (4.3)$$

Where Vi is the voltage at bus i

Vj is the voltage at bus j

Rij is resistance of line connected between bus i and j

Xij is the reactance connected between bus i and j

B_{ij} is the susceptance connected between bus i and j

α is the firing angle of SVC

θ_{ij} is the net phase shift in the line.

The FACTS device must be placed on the most sensitive lines. With the sensitive indices computed for each type of FACTS device, TCSC , SVC and TCPAR should be placed in a line (K) having most positive value and absolute value of sensitivity respectively.

V. Simulation and Results Discussion

The study has been conducted on transient stability of an IEEE 14 BUS system and IEEE 24 BUS system using power world simulator 17.0.

For each system the enhancement of Transient stability is determined by placing different FACTS devices like TCSC, TCPAR and SVC in the optimal location using sensitivity approach method.

The two systems are modeled internally using power world simulator. The internal models includes generator model, exciter model, stabilizers…e.t.c. The following section contains the detailed results.

a) Case study-1: IEEE 14 Bus System

This system consists of 14 buses, 17 line sections, 5 generator buses and 8 load buses.

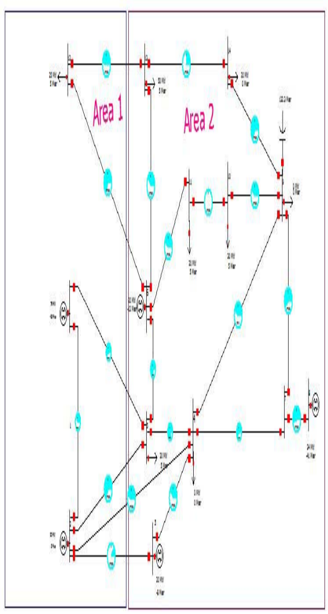

Figure 13 : single line diagram of IEEE 14 bus system

Table 1 : Sensitivity Factors For TCSC, TCPAR In IEEE 14-Bus System

Line	From Bus To Bus	Sensitivity Index			
		TCSC (30%) (a_{ij})	TCSC (40%) (a_{ij})	TCPAR (30%) (b_{ij})	TCPAR (40%) (b_{ij})
1	1-2	-1.2637	-1.3633	-0.0044	-0.0059
2	1-5	-0.4879	-0.5853	-0.0106	-0.0141
3	2-3	-0.0608	-0.0733	-0.1565	-0.0011
4	2-4	-0.1888	-0.2030	-0.0084	-0.0112
5	2-5	-0.1702	-0.1836	-0.0054	-0.0072
6	3-4	-0.0352	-0.0339	-0.0047	-0.0063
7	4-5	-0.1332	-0.1459	-0.0291	-0.0388
8	4-7	-0.5426	-0.7386	0	0
9	4-9	-0.2127	-0.2894	0	0
10	5-6	-0.7320	-0.9964	0	0
11	6-11	-0.0114	-0.0106	0	0
12	6-12	-0.0297	-0.0220	0	0
13	6-13	-0.0713	-0.0460	0	0
14	7-8	-0.1812	-0.2467	0	0
15	7-9	-0.8918	-1.2138	0	0
16	9-10	-0.2503	-0.2487	0	0
17	9-14	-0.0312	-0.0242	0	0
18	10-11	-0.0514	-0.0456	0	0
19	12-13	0.0013	0.0018	0	0
20	13-14	-0.0277	-0.0195	0	0

For this system, from table-1 the following are considered:

- TCSC is placed with a compensation of 40% in the line 13(12-13) and is operated.
- TCPAR is placed with a phase shift of 2 and unity tap ratio.

By using sensitivity approach, the sensitivity index at line 13 is more positive than remaining lines hence the compensation is provided at that line. Similarly the sensitivity index at line 3 is the highest absolute value i.e. -0.1565 and -0.0011 for 30% and 40% compensation of TCPAR.

By placing these devices in a line the transient stability is improved i.e. generator rotor angles, voltages, generator power, accelerated power are improved as shown.

i. *Rotor angle improvement*

The following graphs shows the variation of rotor angle with time and it also shows the enhancement of rotor angle with and without FACTS device during Transient Stability.

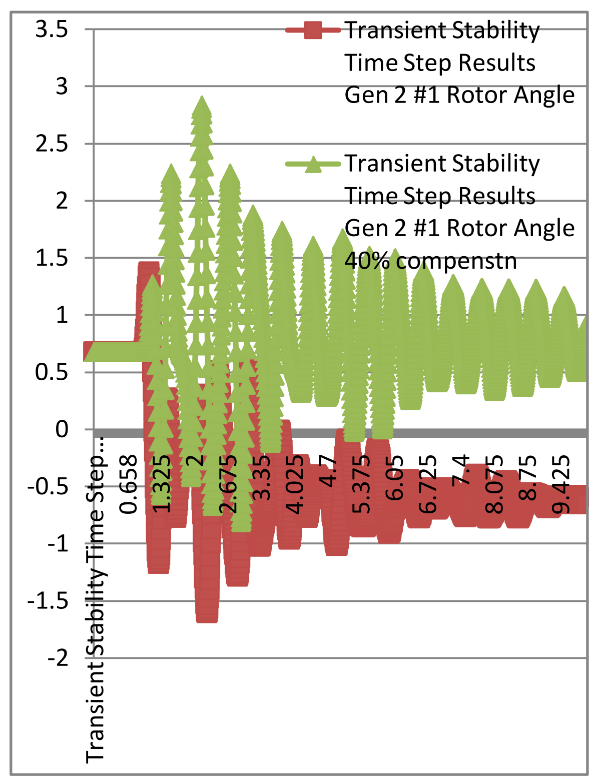

Figure 14 : Generator-2 rotor angle curves with and without compensation

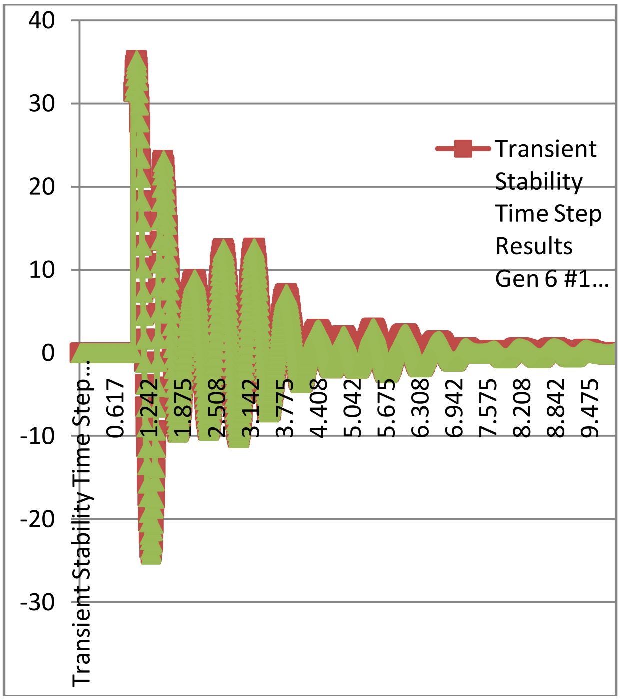

Figure 15 : Generator-6 rotor angle curves with and without TCPAR

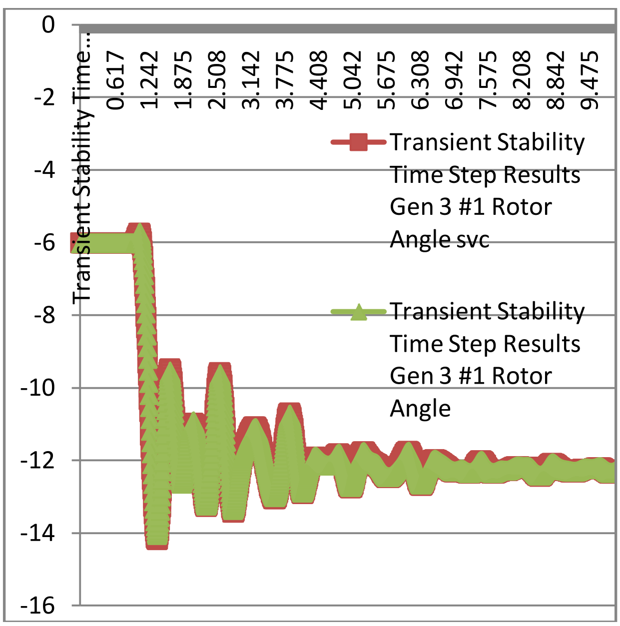

Figure 16 : Generator-3 rotor angle curves with and without SVC

ii. *Voltage Improvement*

The following figures show the plot varying between voltage and time and they also shows the enhancement of voltage by placing FACTS devices in a system during Transient Stability.

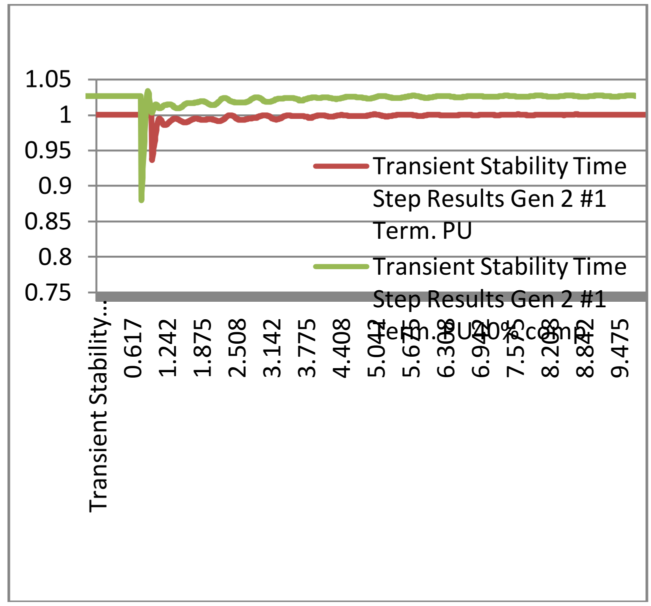

Figure 17 : Generator-2 voltage curves with and without compensation of TCSC

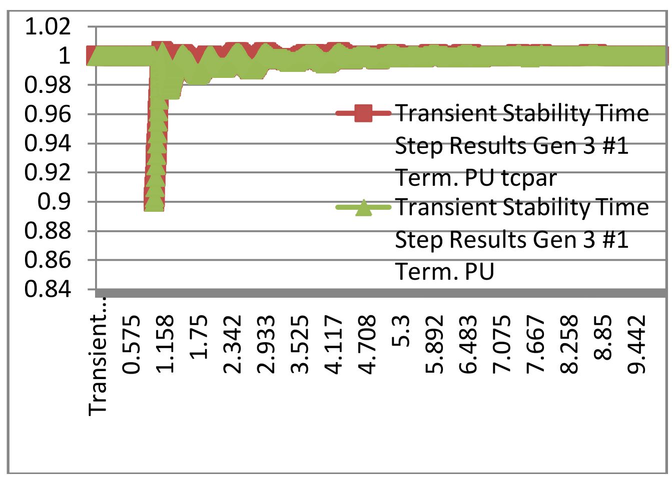

Figure 18 : Generator-3 voltage curves with and without TCPAR

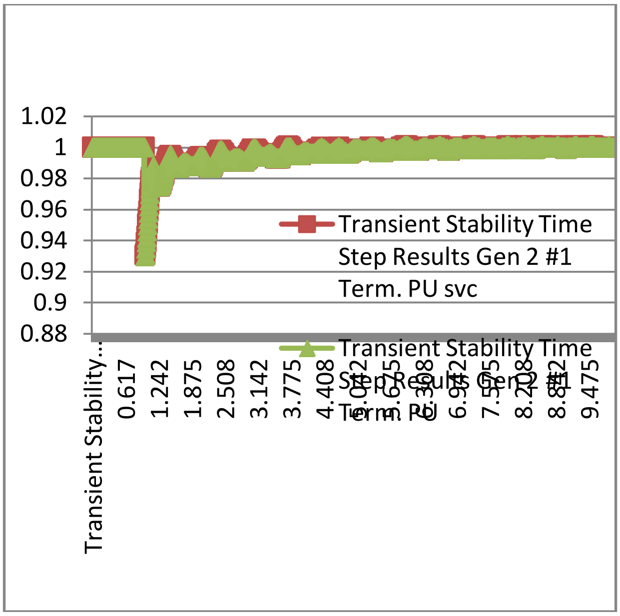

Figure 19 : Generator-2 voltage curves with and without SVC

iii. *Speed Vs Rotor angle*

The following figures show the variation of speed with rotor angle and the enhancement by placing the FACTS devices.

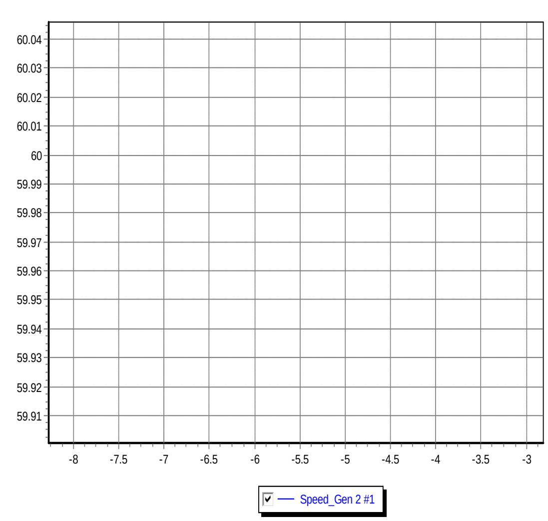

Figure 20: speed vs rotor angle of generator-2 with TCSC

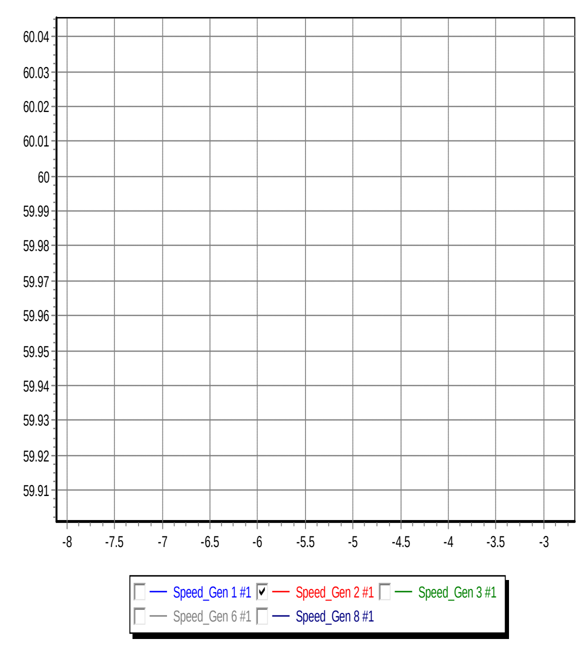

Figure 21 : speed vs rotor angle of generator-2 with TCPAR

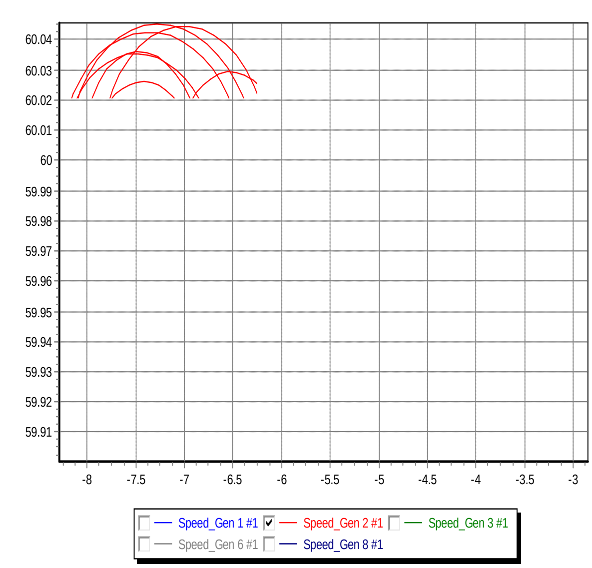

Figure 22 : speed vs rotor angle of generator-2 with SVC

iv. *MVAR terminal*

The following figures show the variation of MVAR with time during Transient stability. The MVAR at the generator terminal decreases by placing the FACTS device as shown.

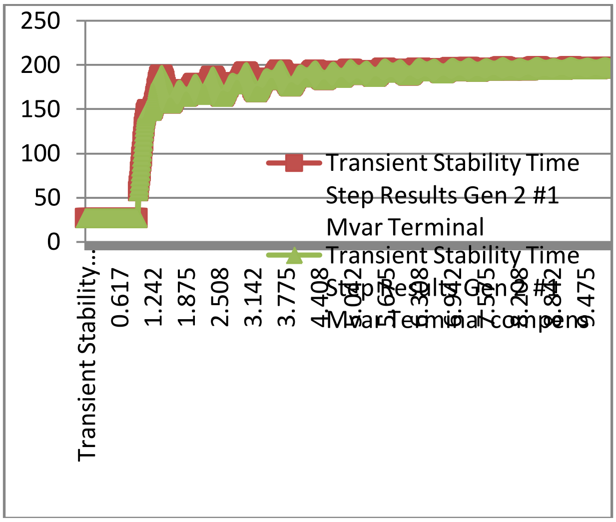

Figure 23 : Generator-2 MVAR with and without TCSC

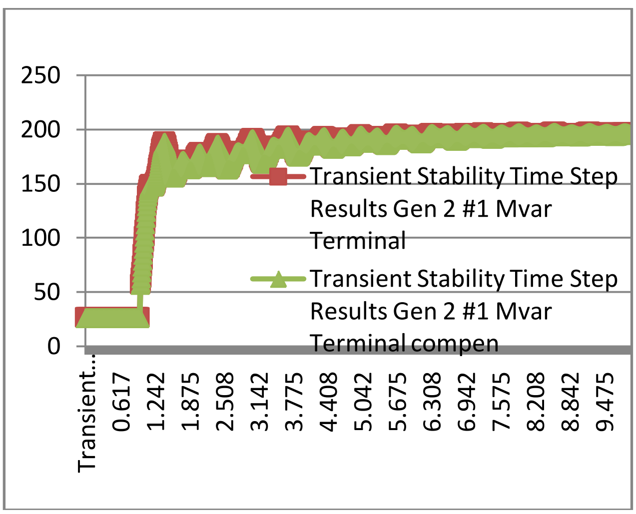

Figure 24 : Generator-2 MVAR with and without TCPAR

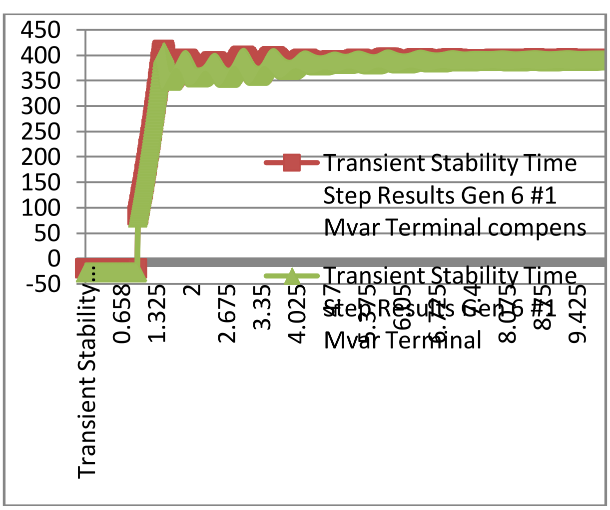

Figure 25 : Generator-6 MVAR with and Without SVC

b) Case Study-2: IEEE 24-BUS system

IEEE-24 bus system consists of 24-buses, 38 line sections, 11 generator buses, 17 load buses as show in the figure.

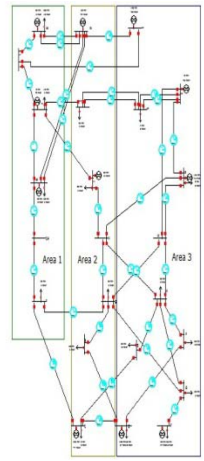

Figure 26 : IEEE 24 BUS system Sensitivity index of IEEE 24-bus system

Table 2 : Sensitivity Factors for TCSC in IEEE 24-Bus System

Line	From Bus To Bus	Sensitivity Index			
		TCSC (30%) (a_{ij})	TCSC (40%) (a_{ij})	TCPAR (30%) (b_{ij})	TCPAR (40%) (b_{ij})
1	1-2	-4.6122	-1.4368	-0.01193	-0.0102
2	1-3	-2.2692	-2.6810	-0.1144	-0.0981
3	1-5	-4.0956	-4.7986	-0.0294	-0.0252
4	2-4	-0.4734	-0.5547	-0.0141	-0.0121
5	2-6	-1.6509	-1.9352	-0.0997	-0.0855
6	3-9	-0.00010312	-0.00012083	0.0030	0.0026
7	3-24	-1.2369	-1.6808	0	0
8	4-9	-5.6109	-6.6787	-0.0368	-0.0312
9	5-10	-2.0481	-2.4232	-0.0168	-0.0144
10	6-10	**-0.0526**	**0.2394**	-0.0076	-0.0065
11	7-8	-0.6334	-0.7419	-0.11033	-0.0945
12	8-9	-0.2668	-0.3152	-0.0210	-0.0180
13	8-10	-0.3654	-0.4317	-0.0210	-0.0180
14	9-11	-0.7221	-0.9812	0	0
15	9-12	-0.4065	-0.5524	0	0
16	10-11	-0.9940	-1.3507	0	0
17	10-12	-0.5586	-0.7590	0	0
18	11-13	-0.0872	-0.1148	0.0323	0.0277
19	11-13	-2.2889	-3.0141	-0.0288	-0.0247
20	12-13	-0.4230	-0.5571	0.0210	0.01810
21	12-23	-0.3148	-0.4136	-0.0544	-0.0466
22	13-23	-0.0845	-0.1113	-0.0868	-0.0744
23	14-16	-0.1070	-0.1409	-0.0028	-0.0024
24	15-16	-0.00052124	-0.00070922	-0.0027	-0.0024
25	15-21	-0.0190	-0.0250	0.0065	0.0056
26	15-21	-0.0190	-0.0250	0.0065	0.0056
27	15-24	-1.0830	-1.4255	0.0065	0.0056
28	16-17	-0.1859	-0.2448	0.0039	0.0033
29	16-19	-0.6409	-0.8440	-0.0031	-0.0027
30	17-18	-0.2637	-0.3473	-0.0012	-0.0010
31	17-22	-0.0100	-0.0133	**0.1326**	**0.1136**
32	18-21	-0.0876	-0.1151	0.0058	0.0050
33	18-21	-0.0876	-0.1151	0.0058	0.0050
34	19-20	-0.1634	-0.2146	0.0147	0.0126
35	19-20	-0.1634	-0.2146	0.0147	0.0126
36	20-23	-0.1812	-0.2380	0.0048	0.0041
37	20-23	-0.1812	-0.2380	0.0048	0.0041
38	21-22	-0.0211	-0.0278	0.0762	0.0653

The following table- shows the sensitivity index for IEEE 24-bus system.

From the table below the line 10(6-10) has more positive sensitivity index at 30% and 40% compensation of TCSC. Similarly, the line 31(17-22) has high absolute value at 30% and 40% compensation.

For this system, from table above the following are considered:

- TCSC is placed with a compensation of 40% in the line 10(6-10) and is operated.
- TCPAR is placed in the line 31(17-22) with a phase shift of 2 and unity tap ratio.

By using sensitivity approach, the sensitivity index at line 10 is more positive than remaining lines hence the compensation is provided at that line. Similarly the sensitivity index at line 31 is the highest absolute value i.e. 0.1326 and 0.1136 for 30% and 40% compensation of TCPAR.

By placing these devices in a line the transient stability is improved i.e. generator rotor angles, voltages, generator power, accelerated power and MVAR are improved as shown.

c) Rotor angle improvement

The following graphs shows the variation of rotor angle with time and it also shows the enhancement of rotor angle with and without FACTS device during Transient Stability.

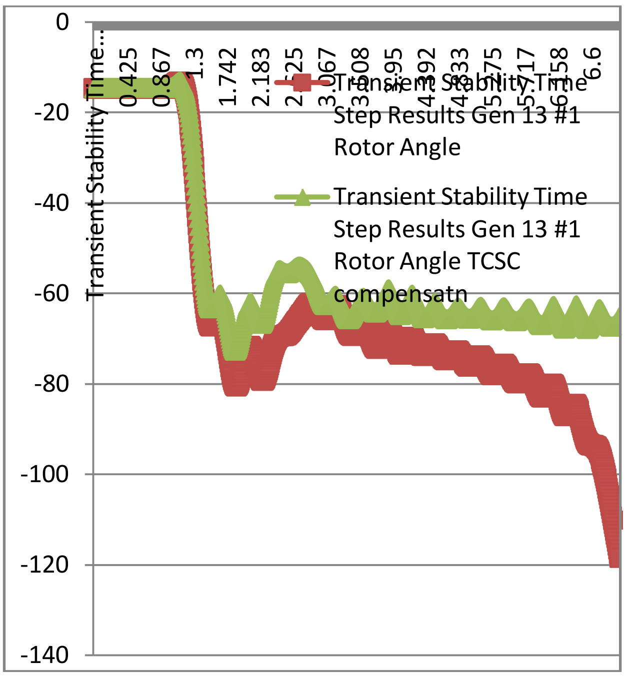

Figure 27 : Generator-13 rotor angle curves with and without compensation of TCSC

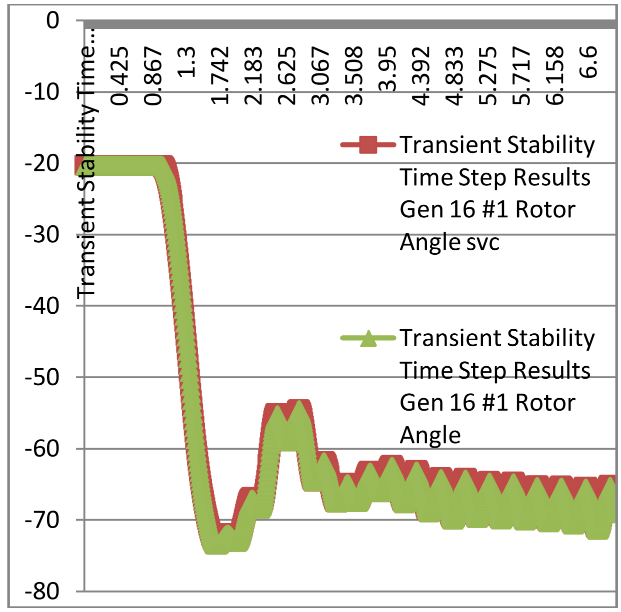

Figure 28 : Generator-16 rotor angle curves with and without compensation of SVC

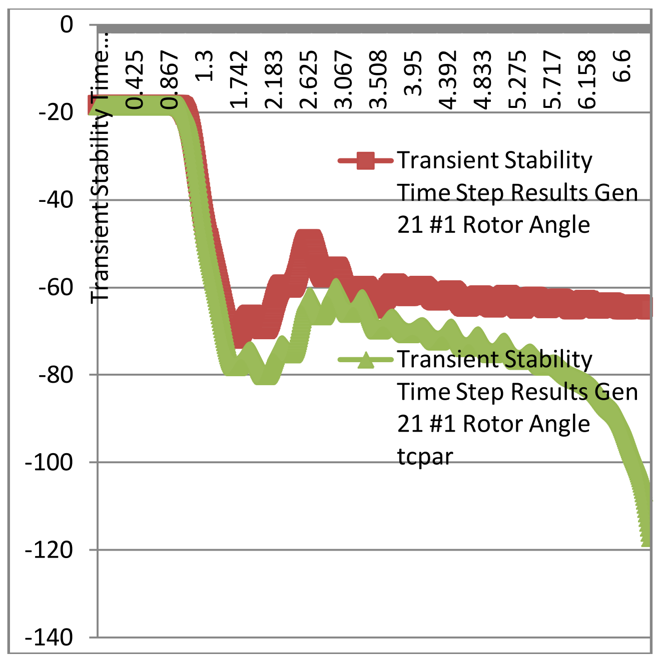

Figure 29 : Generator-21 rotor angle curves with and without compensation of TCPAR

d) Voltage Improvement

The voltage of the system is improved after the transient occurred by using the FACTS devices such as TCSC, TCPAR and SVC as shown below.

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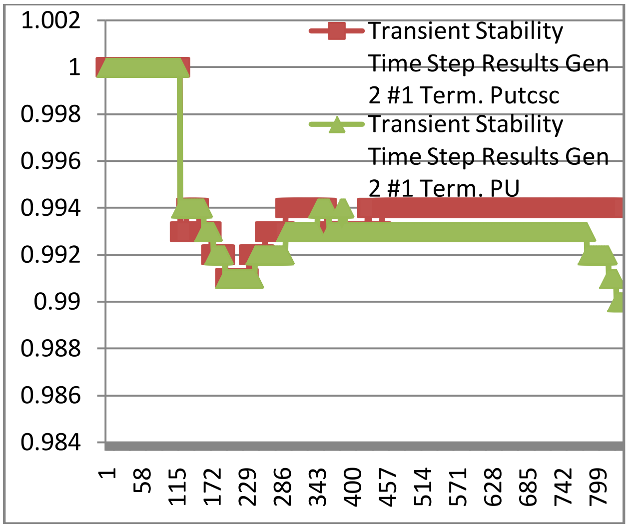

Figure 30 : Generator-2 voltage curves with and without compensation of TCSC

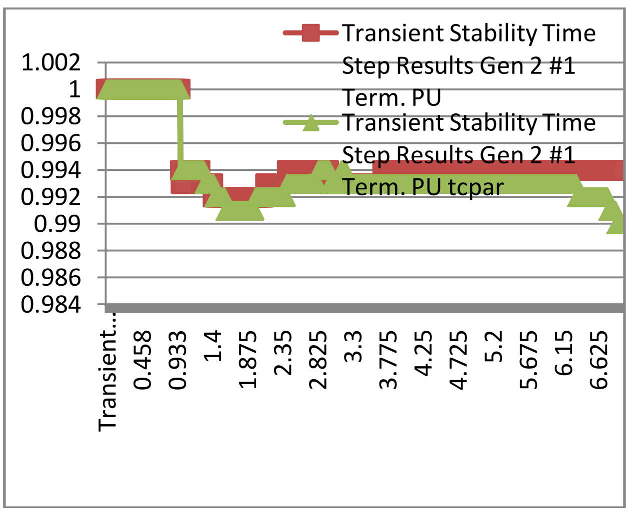

Figure 31 : Generator-2 voltage curves with and without compensation of TCPAR

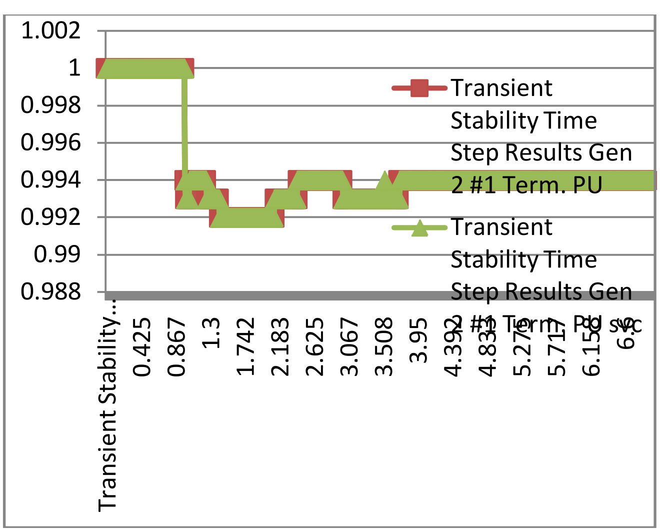

Figure 32 : Generator-2 voltage curves with and without compensation of SVC Speed vs rotor angle curves

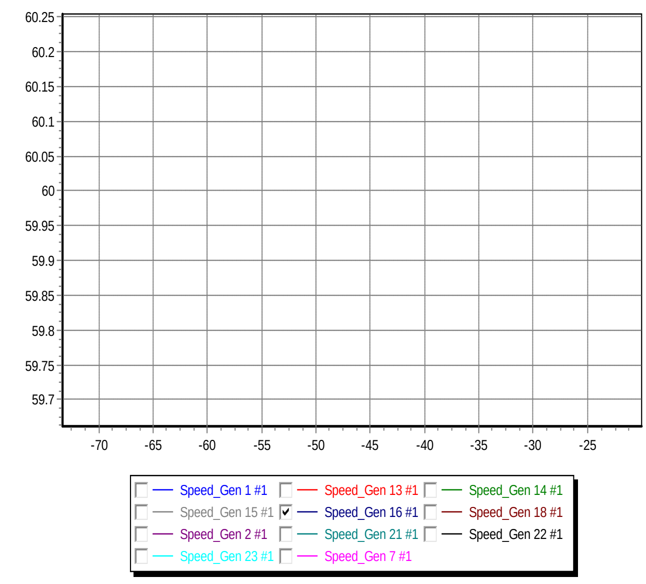

Figure 33 : Generator-16 speed vs rotor angle curves with compensation of TCSC

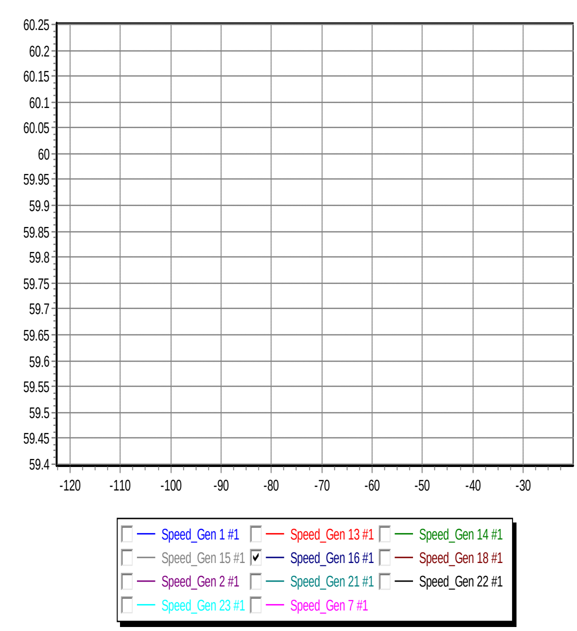

Figure 34 : Generator-16 speed vs rotor angle curves with compensation of TCPAR

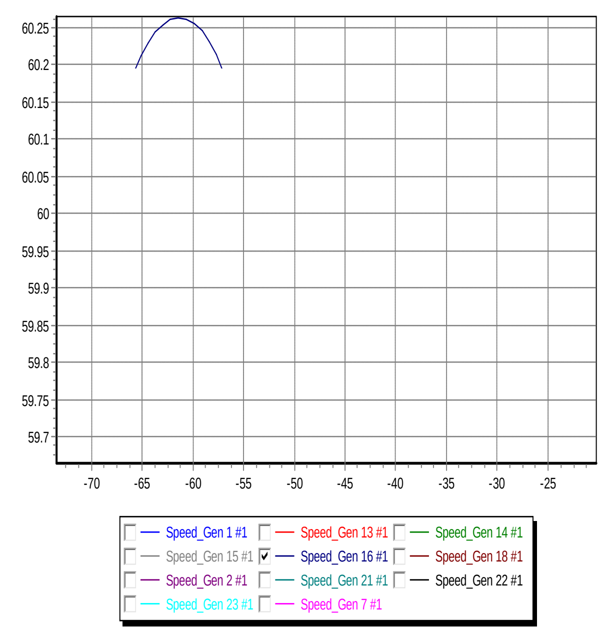

Figure 35 : Generator-16 speed vs rotor angle curves with compensation of SVC

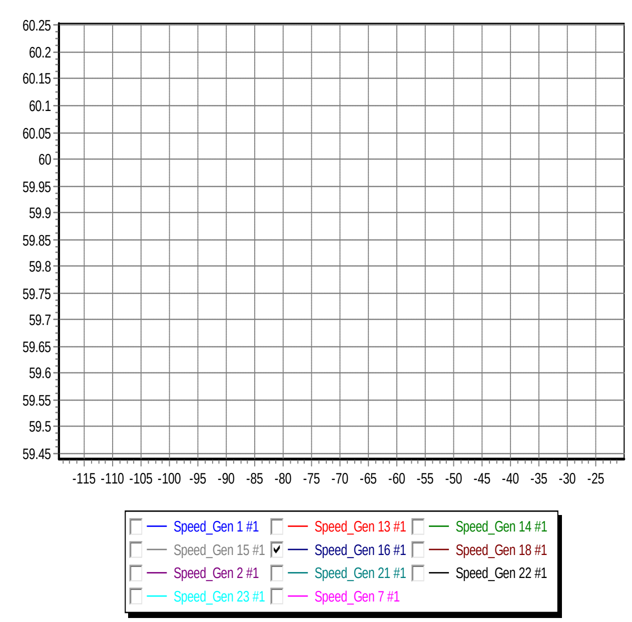

Figure 36 : Generator-16 speed vs rotor angle curves before compensation

VI. Mvar Terminal

The following figures show the variation of MVAR with time during Transient stability. The MVAR at the generator terminal decreases by placing the FACTS device as shown.

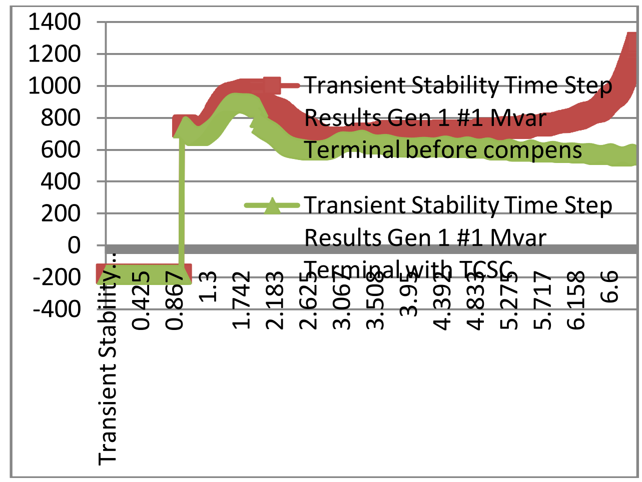

Figure 37 : Generator-1 MVAR terminal with and without compensation of TCSC

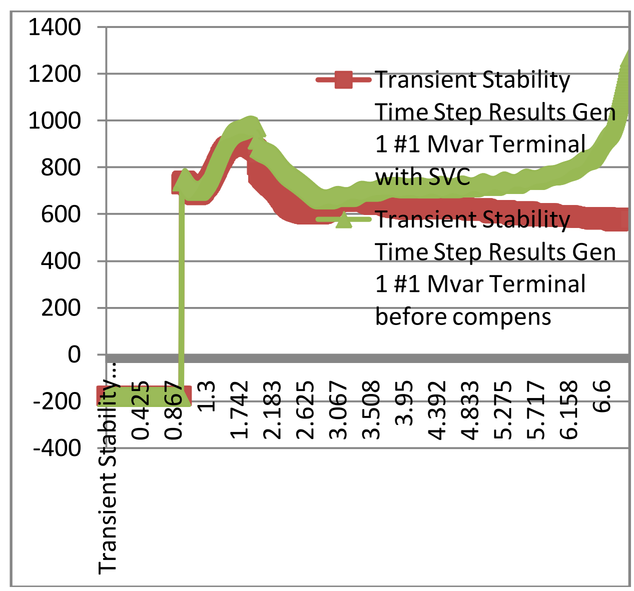

Figure 38 : Generator-1 MVAR terminal with and without compensation of SVC

VII. Conclusion

In this paper a simple sensitivity method is used for determining optimum location of FACTS devices for improving the transient stability. Based on sensitivity index the device is located. The rotor angle, voltage, speed and MVAR terminal of generator are improved using FACTS devices TCSC, TCPAR, SVC as described in this paper.

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ASIC Design, Implementation and Exploration on High Speed Parallel Multiplier

By Y. Narasimha Rao, DR. G. Samuel Vara Prasada Raju & Penmetsa V Krishna Raja
GITAM University, India

Abstract- Designing multiplier is always a challenging and interesting job, in order to satisfy user needs as per demand. Vedic multiplier is prominent system for faster result and optimized circuit design. In any digital system the throughput and power consumption decides the performance. The present work mainly concentrated on Vedic multiplier power consumption and throughput. In much faster computing and parallel processing architectures, pipeline motivates for higher throughput. This is motivated to incorporate pipeline in the present work to enhance the performance of the Vedic multiplier. In the present paper, area and power consumption is also taken into consideration along with throughput. These parameters are compared for different fast adders such as RCA, CSLA, LFA, BKA, KGA in Vedic multiplier. The Vedic multipliers are designed and analysed using Cadense RTL Compiler v08.10.

Keywords: throughput, power consumption, area, pipeline, fast adders, vedic multiplier.

GJRE-F Classification : FOR Code: 100699

ASICDESIGNIMPLEMENTATIONANDEXPLORATIONONHIGHSPEEDPARALLELMULTIPLIER

Strictly as per the compliance and regulations of :

ASIC Design, Implementation and Exploration on High Speed Parallel Multiplier

Y. Narasimha Rao [α], DR. G. Samuel Vara Prasada Raju [σ] & Penmetsa V Krishna Raja [ρ]

Abstract- Designing multiplier is always a challenging and interesting job, in order to satisfy user needs as per demand. Vedic multiplier is prominent system for faster result and optimized circuit design. In any digital system the throughput and power consumption decides the performance. The present work mainly concentrated on Vedic multiplier power consumption and throughput. In much faster computing and parallel processing architectures, pipeline motivates for higher throughput. This is motivated to incorporate pipeline in the present work to enhance the performance of the Vedic multiplier. In the present paper, area and power consumption is also taken into consideration along with throughput. These parameters are compared for different fast adders such as RCA, CSLA, LFA, BKA, KGA in Vedic multiplier. The Vedic multipliers are designed and analysed using Cadense RTL Compiler v08.10.

Keywords: throughput, power consumption, area, pipeline, fast adders, vedic multiplier.

I. Introduction

Fast adders and multiplications are ever needed in many DSP systems Multiplication operations also form the basis for other complex operations such as convolution, Discrete Fourier Transform, Fast Fourier Transforms, etc. With ever increasing need for faster clock frequency it becomes imperative to have faster arithmetic unit [1].Another important area on which is required to concentrate is the power dissipation and speed. There is always an interrelation between power dissipated and speed of operation ever known to all. Vedic multiplier is famous for fast operation and less power consumption with respect to bit size. Vedic multiplier is adopted from ancient Indian mathematics which is stated in Atharva Veda. His Holiness Jagadguru Shankaracharya Bharati Krishna Teerthaji Maharaja (1884- 1960) comprised andgave mathematical explanation while discussingit for various applications. Swamiji constructed 16 formulae and 16 sub formulae after extensive research in Atharva Veda [2] [3].A general block diagram of Vedic Multiplier is shown in figure 1.

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Author σ: Professor, Department of Computer Science, Andhra University, Visakhapatnam, AP, India.
Author ρ: AIMS College of Engineering, Mummidivaram, Amalapuram East Godavari, AP, India.

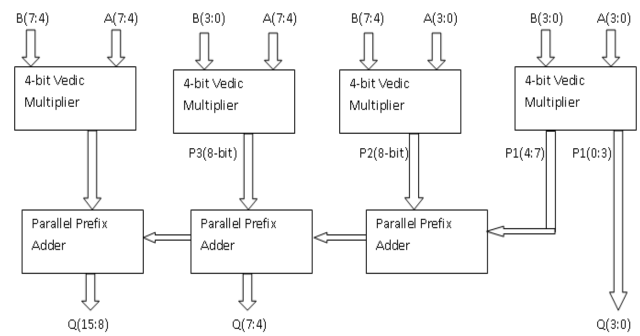

Figure 1 : Block diagram of Vedic Multiplier

There are many adders effectively working in many different types of multipliers. A time, area, and power consumption is studies in previous work [4][5], which are the base work for the present paper. The Carry Look-Ahead Adder (CLA) requires large area and consumes high power with respect to the bit size. So there is a Speed limitation with respect to bit size [6]. Unlike CLA the carry-select adder (CSA) increases its are a requirements to enhance its speed performance. In CSA irrespective of arrival of carry-in, the sum will arrive at output. So it will take less time than other methods to calculate the sum [7][8]. In the proposed work Parallel Prefix Adders (PPA) are selected because addition is done quicker than traditional adders. The large fan-out in PPA can be eliminated by increasing the number of levels of cells and buffers [5]. The Kogg-stone Adder (KSA) is most widely used adder for high performance. It has very low fan-out which makes it performance high [9]. The Brent-Kung adder (BKA) requires less area and minimum interconnecting wires than Kogge-Stone adder [9][10]. The Ladner-Fischer Adder (LFA) adder requires less area when compared with KSA, but has large fan-out [9][10].

II. Motivation

In the previous paper few parameters are measured and compared for Vedic Multiplier with different fast adders. Based on these results it is observed that LFA is selected with less area and less power consumption [5]. Hence the next work is extended with implementation of Pipelined Vedic Multiplier (PVM) with LFA. So In the previous work it is tested and observed that a good throughput is achieved in PVM when compared with Traditional Vedic Multiplier

(TVM) [4]. It is also analysed that as the pipeline is incorporated in traditional circuit, the cell area increased little more when compared with traditional Vedic multiplier. The increase in cell area also leads more power consumption. These analyses done with Ladner Fischer adder (LFA)under Parallel Prefix Adder (PPA) structure [4]. Although the circuit complexity increased in the PVM [4] it is observed that it has relatively less power consumption and better throughput when compared with other existing techniques. This motivates us to measure all the parameters of PVM with all adders. This may lead to a new significant of work. In the present paper the PVM is also tested with various other adders for identifying better results and to find flaws with other adders. This work will be more interesting for future researchers.

III. Proposed Work

In the present work a new architecture is proposed for Vedic Multiplier. Although this method is proposed in my past paper [4], but in the present paper pipeline is applied to all different types of fast adders as case study and makes us flexible to select an adder according to the requirement. It is observed some exciting results with each adder. Each adder is idiosyncratic for a specific application. In the proposed work two 8-bit data A (0:7) and B (0:7) is taken for multiplication.

In the present method pipeline stages are integrated at individual stages of PPA as shown in figure 1[4]. Figure 2 is showing a comprised block diagram of Pipelined Vedic Multiplier (PVM). After adding these pipeline stages the circuit area increases and hence the power consumption also increases when compared with TVM. But this varies from one adder to another adder. So the pipeline technology is applied to all adders and tested to choose best adder with high performance. As each adder is peculiar for a parameter we can consider any adder as per the requirement, and we can simply neglect other adders as they are important in some other area.

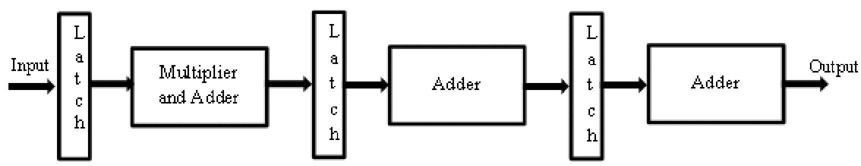

Figure 2 : Block Diagram of Pipelined Vedic Multiplier

In figure 2 latches are place in between input, multiplier and adders. Initially all input are entered into 4-bit Vedic multiplier through first stage of latches. The partial product generated at first stage will enter into next stage latches and the second partial product will be generated and passed through at third stage latches and final product will be produced at last adder circuit. The adder circuit implies all adders such as RCA, CSLA, LFA, BKA, and KGA.

IV. Results

The circuit is designed and analysed using Cadense RTL Compiler v08.10.The circuit is tested on different adders like RCA, CSLA, LFA, BKA, and KGA with and without pipeline technology. Table 1 is showing measured parameters such as Area, Throughput and Power Consumption in TVM and PVM with different adders. The area represented in terms of number of gates, Throughput measured in Nano-seconds (ns) and power consumption indicated in milli-watts (mw). Figure 3 and Figure 4 are showing relative work between TVM and PVM. Figure 5 is showing RTL schematic of a Pipelined Vedic Multiplier. Figure 6.1a to 6.1c is showing simulation results of Brent-Kung adder (BKA) showing cell area, delay and power consumption respectively. Figure 7.1a to 7.1c is showing simulation results of Carry Select adder (CSLA) showing cell area, delay and power consumption respectively. Figure 8.1a to 8.1c is showing simulation results of Kogge-Stone adder (KGA) showing cell area, delay and power consumption respectively. Figure 9.1a to 9.1c is showing simulation results of Ripple Carry adder (RCA) showing cell area, delay and power consumption respectively.

Table 1 : Comparision Table of Vedic Multiplier with different adders

	Regular Vedic Multiplier	RCA	CSLA	PPA		
				LFA	BKA	KGA
Area	348	420	309	415	411	410
Throughput	15	12ns	9ns	10ns	10ns	10ns
Power	10	57.2mW	42.2mW	57.3mW	57.4mW	57.0mW

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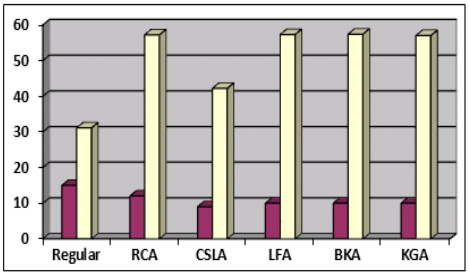


Figure 3 : Comparision of Throughput (ns) and Power Consumption (mW) between TVM and PVM

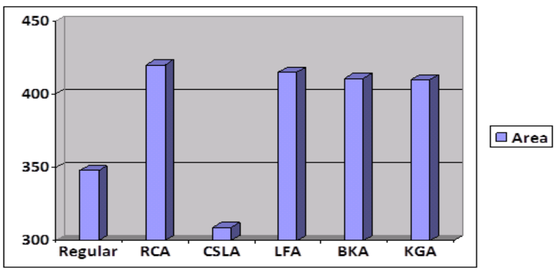


Figure 4 : Comparision of area (no of Gates) between TVM and PVM

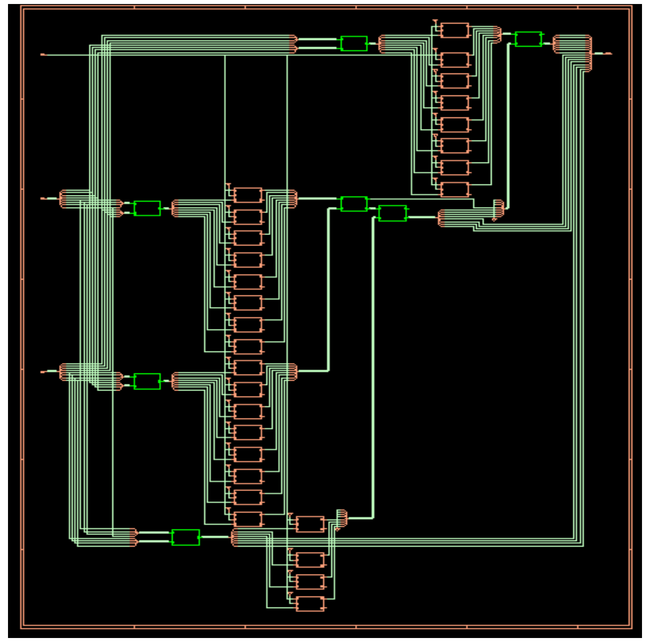
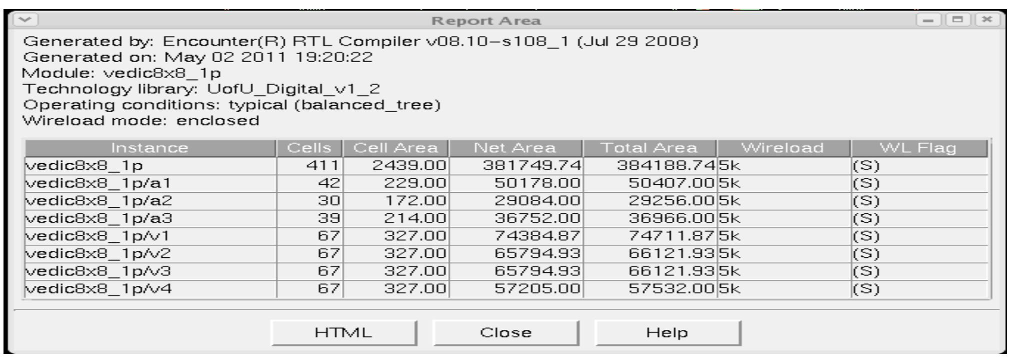


Figure 5 : RTL Schematic of Pipelined Vedic Multiplier



Report Area

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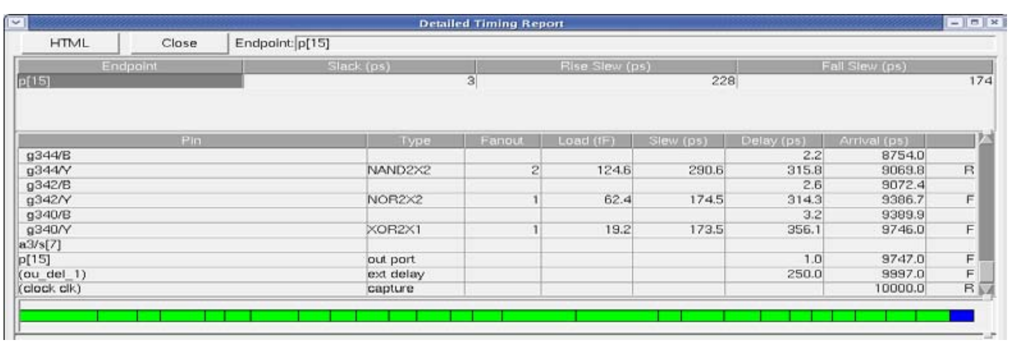
Generated on: May 02 2011 19:20:22
Module: vedic8x8_1p
Technology library: UofU_Digital_v1_2
Operating conditions: typical (balanced_tree)
Wireload mode: enclosed

Instance	Cells	Cell Area	Net Area	Total Area	Wireload	WL Flag
vedic8x8_1p	411	2439.00	381749.74	384188.74	5k	(S)
vedic8x8_1p/a1	42	229.00	50178.00	50407.00	5k	(S)
vedic8x8_1p/a2	30	172.00	29084.00	29256.00	5k	(S)
vedic8x8_1p/a3	39	214.00	36752.00	36966.00	5k	(S)
vedic8x8_1p/v1	67	327.00	74384.87	74711.87	5k	(S)
vedic8x8_1p/v2	67	327.00	65794.93	66121.93	5k	(S)
vedic8x8_1p/v3	67	327.00	65794.93	66121.93	5k	(S)
vedic8x8_1p/v4	67	327.00	57205.00	57532.00	5k	(S)

HTML Close Help

Figure 6.1a : Simulation Results of Cell area in BKA



Detailed Timing Report

HTML Close Endpoint: p[15]

Endpoint	Slack (ps)	Rise Slew (ps)	Fall Slew (ps)
p[15]	3	228	174

Pin	Type	Fanout	Load (fF)	Slew (ps)	Delay (ps)	Arrival (ps)	
g344/B					2.2	8754.0	
g344/Y	NAND2X2	2	124.6	290.6	315.8	9069.8	R
g342/B					2.6	9072.4	
g342/Y	NOR2X2	1	62.4	174.5	314.3	9386.7	F
g340/B					3.2	9389.9	
g340/Y	XOR2X1	1	19.2	173.5	356.1	9746.0	F
a3/s[7]							
p[15]	out port				1.0	9747.0	F
(ou_del_1)	ext delay				250.0	9997.0	F
(clock clk)	capture					10000.0	R

Figure 6.1b : Simulation Results of delay in BKA

Report Power

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Operating conditions: typical (balanced_tree)
Wireload mode: enclosed

Instance	Cells	Leakage (nW)	Internal (nW)	Net (nW)	Switching (nW)
vedic8x8_1p	411	50.94	39800011.75	17581337.50	57381349.25
vedic8x8_1p/a1	42	4.61	4196745.95	2998518.75	7195264.70
vedic8x8_1p/a2	30	3.40	3713022.49	2176618.75	5889641.24
vedic8x8_1p/a3	39	4.18	3556243.10	1820800.00	5377043.10
vedic8x8_1p/v1	67	6.40	2091594.63	1500437.50	3592032.13
vedic8x8_1p/v2	67	6.40	2278547.23	1752593.75	4031140.98
vedic8x8_1p/v3	67	6.40	2253797.79	1707781.25	3961579.04
vedic8x8_1p/v4	67	6.40	2526712.77	1965981.25	4492694.02

HTML Close Help

Figure 6.1c : Simulation Results of Power Consumption in BKA

Report Area

Generated by: Encounter(R) RTL Compiler v08.10–s108_1 (Jul 29 2008)
Generated on: May 02 2011 19:43:37
Module: vedic8x8_1p
Technology library: UofU_Digital_v1_2
Operating conditions: typical (balanced_tree)
Wireload mode: enclosed

Instance	Cells	Cell Area	Net Area	Total Area	Wireload	WL Flag
vedic8x8_1p	309	1941.00	323576.74	325517.74	5k	(S)
vedic8x8_1p/a1	5	45.00	28123.00	28168.00	5k	(S)
vedic8x8_1p/a1/A1	0	0.00	0.00	0.00	5k	(S)
vedic8x8_1p/a1/A2	0	0.00	0.00	0.00	5k	(S)
vedic8x8_1p/a1/A3	0	0.00	0.00	0.00	5k	(S)
vedic8x8_1p/a1/M1	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M2	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M3	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M4	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M5	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a2	4	36.00	14219.00	14255.00	5k	(S)

HTML Close Help

Figure 7.1a : Simulation Results of Cell area in CSLA

Detailed Timing Report

HTML Close Endpoint: p2b_reg[7]/D

Endpoint	Slack (ps)	Rise Slew (ps)	Fall Slew (ps)
p2b_reg[7]/D	11	319	528

Pin	Type	Fanout	Load (fF)	Slew (ps)	Delay (ps)	Arrival (ps)	
g522/A					2.7	6931.6	
g522/Y	INVX2	2	99.6	186.1	338.9	7270.5	F
g520/B					2.2	7272.7	
g520/Y	XNOR2X1	2	99.7	461.4	540.7	7813.4	R
g517/A					1.6	7815.0	
g517/Y	OAI22X1	1	45.7	527.7	751.2	8566.2	F
v3/z[7]							
p2b_reg[7]/D	DCBX1				2.3	8568.5	
p2b_reg[7]/CLK	setup			400.0	420.8	8989.3	R
(clock clk)	capture					9000.0	R

Figure 7.1b: Simulation Results of delay in CSLA

Report Power

Generated by: Encounter(R) RTL Compiler v08.10–s108_1 (Jul 29 2008)
Generated on: May 02 2011 19:43:02
Module: vedic8x8_1p
Technology library: UofU_Digital_v1_2
Operating conditions: typical (balanced_tree)
Wireload mode: enclosed

Instance	Cells	Leakage (nW)	Internal (nW)	Net (nW)	Switching (nW)
vedic8x8_1p	309	41.44	31491493.72	10709756.94	42201250.66
vedic8x8_1p/a1	5	1.01	341542.02	376925.00	718467.02
vedic8x8_1p/a1/A1	0	0.00	0.00	84175.00	84175.00
vedic8x8_1p/a1/A2	0	0.00	0.00	186150.00	186150.00
vedic8x8_1p/a1/A3	0	0.00	0.00	187600.00	187600.00
vedic8x8_1p/a1/M1	1	0.20	65202.93	9000.00	74202.93
vedic8x8_1p/a1/M2	1	0.20	56377.51	7200.00	63577.51
vedic8x8_1p/a1/M3	1	0.20	73320.53	10800.00	84120.53
vedic8x8_1p/a1/M4	1	0.20	73320.53	10800.00	84120.53
vedic8x8_1p/a1/M5	1	0.20	73320.53	10800.00	84120.53
vedic8x8_1p/a2	4	0.81	277479.61	229400.00	506879.61

HTML Close Help

Figure 7.1c : Simulation Results of Power Consumption in CSLA

Report Area

Generated by: Encounter(R) RTL Compiler v08.10–s108_1 (Jul 29 2008)
Generated on: May 02 2011 19:25:08
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Technology library: UofU_Digital_v1_2
Operating conditions: typical (balanced_tree)
Wireload mode: enclosed

Instance	Cells	Cell Area	Net Area	Total Area	Wireload	WL Flag
vedic8x8_1p	410	2435.00	381105.74	383540.74	5k	(S)
vedic8x8_1p/a1	41	224.00	50818.00	51042.00	5k	(S)
vedic8x8_1p/a2	30	169.00	29082.00	29251.00	5k	(S)
vedic8x8_1p/a3	39	218.00	35470.00	35688.00	5k	(S)
vedic8x8_1p/v1	67	327.00	74384.87	74711.87	5k	(S)
vedic8x8_1p/v2	67	327.00	65794.93	66121.93	5k	(S)
vedic8x8_1p/v3	67	327.00	65794.93	66121.93	5k	(S)
vedic8x8_1p/v4	67	327.00	57205.00	57532.00	5k	(S)

HTML Close Help

Figure 8.1a : Simulation Results of Cell area in KGA

Detailed Timing Report

HTML Close Endpoint: p[15]

Endpoint	Slack (ps)	Rise Slew (ps)	Fall Slew (ps)
p[15]	10	228	174

Pin	Type	Fanout	Load (fF)	Slew (ps)	Delay (ps)	Arrival (ps)	
g328/B					2.2	8742.3	
g328/Y	NAND2X2	2	125.2	229.9	296.4	9038.7	F
g326/B					2.6	9041.3	
g326/Y	NOR2X2	1	62.5	157.3	271.0	9312.3	R
g324/B					3.2	9315.5	
g324/Y	XOR2X1	1	19.2	227.6	424.0	9739.5	R
a3/S[7]							
p[15]	out port				1.0	9740.5	R
(ou_del_1)	ext delay				250.0	9990.5	R
(clock clk)	capture					10000.0	R

Figure 8.1b : Simulation Results of delay in KGA

Report Power

Generated by: Encounter(R) RTL Compiler v08.10–s108_1 (Jul 29 2008)
Generated on: May 02 2011 19:25:25
Module: vedic8x8_1p
Technology library: UofU_Digital_v1_2
Operating conditions: typical (balanced_tree)
Wireload mode: enclosed

Instance	Cells	Leakage (nW)	Internal (nW)	Net (nW)	Switching (nW)
vedic8x8_1p	410	50.87	39660450.50	17427781.25	57088231.75
vedic8x8_1p/a1	41	4.50	4152090.20	2987956.25	7140046.45
vedic8x8_1p/a2	30	3.31	3698058.63	2041925.00	5739983.63
vedic8x8_1p/a3	39	4.32	3474620.14	1723243.75	5197863.89
vedic8x8_1p/v1	67	6.40	2091594.63	1500437.50	3592032.13
vedic8x8_1p/v2	67	6.40	2278547.23	1752593.75	4031140.98
vedic8x8_1p/v3	67	6.40	2253797.79	1707781.25	3961579.04
vedic8x8_1p/v4	67	6.40	2526712.77	1965981.25	4492694.02

HTML Close Help

Figure 8.1c : Simulation results of Power Consumption in KGA

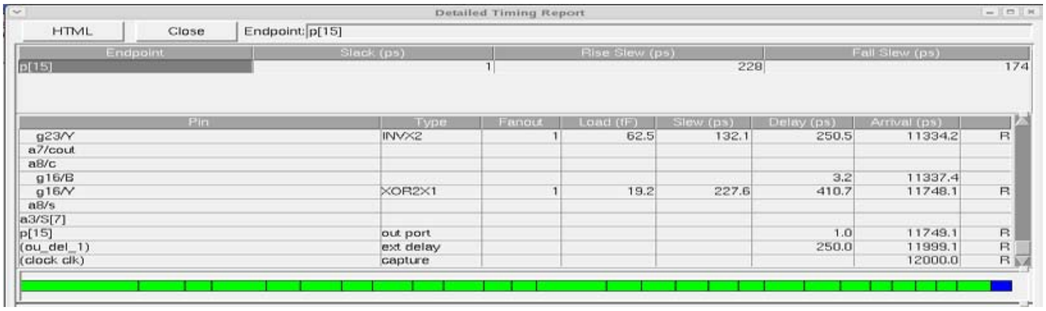
Report Area

Generated by: Encounter(R) RTL Compiler v08.10–s108_1 (Jul 29 2008)
Generated on: May 02 2011 19:45:05
Module: vedic8x8_1p
Technology library: UofU_Digital_v1_2
Operating conditions: typical (balanced_tree)
Wireload mode: enclosed

Instance	Cells	Cell Area	Net Area	Total Area	Wireload	WL Flag
vedic8x8_1p	309	1941.00	323576.74	325517.74	5k	(S)
vedic8x8_1p/a1	5	45.00	28123.00	28168.00	5k	(S)
vedic8x8_1p/a1/A1	0	0.00	0.00	0.00	5k	(S)
vedic8x8_1p/a1/A2	0	0.00	0.00	0.00	5k	(S)
vedic8x8_1p/a1/A3	0	0.00	0.00	0.00	5k	(S)
vedic8x8_1p/a1/M1	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M2	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M3	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M4	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a1/M5	1	9.00	0.00	9.00	5k	(S)
vedic8x8_1p/a2	4	36.00	14219.00	14255.00	5k	(S)
vedic8x8_1p/a2/A1	0	[illegible]	[illegible]	[illegible]	5k	(S)

HTML Close Help

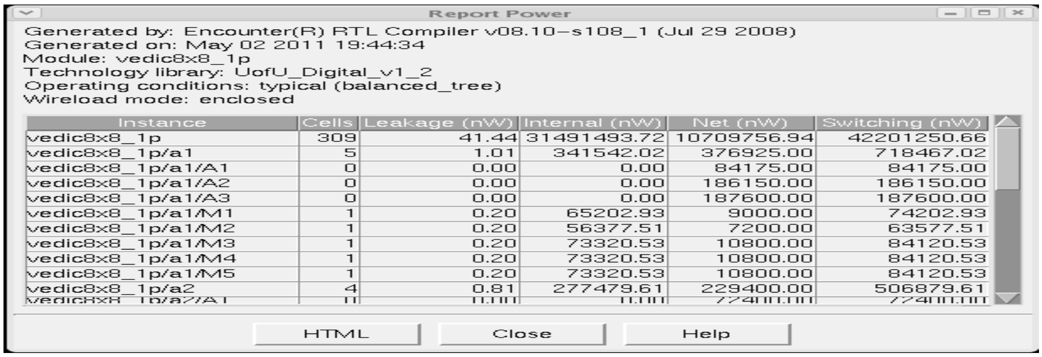
Figure 9.1a : Simulation Results of Cell area in RCA



Endpoint	Slack (ps)	Rise Slew (ps)	Fall Slew (ps)
p[15]	1	228	174

Pin	Type	Fanout	Load (fF)	Slew (ps)	Delay (ps)	Arrival (ps)	
g23/Y	INVX2	1	62.5	132.1	250.5	11334.2	R
a7/cout							
a8/c							
g16/B					3.2	11337.4	
g16/Y	XOR2X1	1	19.2	227.6	410.7	11748.1	R
a8/s							
a3/S[7]							
p[15]	out port				1.0	11749.1	R
(ou_del_1)	ext delay				250.0	11999.1	R
(clock clk)	capture					12000.0	R

Figure 9.1b : Simulation Results of delay in RCA



Instance	Cells	Leakage (nW)	Internal (nW)	Net (nW)	Switching (nW)
vedic8x8_1p	309	41.44	31491493.72	10709756.94	42201250.66
vedic8x8_1p/a1	5	1.01	341542.02	376925.00	718467.02
vedic8x8_1p/a1/A1	0	0.00	0.00	84175.00	84175.00
vedic8x8_1p/a1/A2	0	0.00	0.00	186150.00	186150.00
vedic8x8_1p/a1/A3	0	0.00	0.00	187600.00	187600.00
vedic8x8_1p/a1/M1	1	0.20	65202.93	9000.00	74202.93
vedic8x8_1p/a1/M2	1	0.20	56377.51	7200.00	63577.51
vedic8x8_1p/a1/M3	1	0.20	73320.53	10800.00	84120.53
vedic8x8_1p/a1/M4	1	0.20	73320.53	10800.00	84120.53
vedic8x8_1p/a1/M5	1	0.20	73320.53	10800.00	84120.53
vedic8x8_1p/a2	4	0.81	277479.61	229400.00	506879.61

Figure 9.1c : Simulation Results of Power Consumption in RCA

V. Conclusion

The Traditional Vedic Multiplier consumes less power as it circuit complexity is simple. But the data speed is slow in TVM. In pipeline Vedic Multiplier while first partial product is generating the second input (next 8-bit data) can be fetched into the multiplier. A High throughput is observed in Pipelined Vedic multiplier when compared with Traditional Vedic Multiplier. In parallel prefix adders a constant throughput is achieved. But KGA could be best adder as it has less number of gates and consuming less power than other parallel prefix adders. Overall the performance of the pipelined Vedic Multiplier is high when compared with Regular Vedic Multiplier.

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Biography

Mr. Y. Narasimha Rao, working as Assistant professor, in the department of Information technology, GITAM University, Visakhapatnam, has more than 10 years academic experience. He has completed his Masters degree from Acharya Nagarjuna University. He has published couple of research papers in reputed international journals and conferences. Presently he is doing his research work in Andhra University. His research of interest is Parallel processing, Advanced computer architecture, Cryptography algorithms and Network security.

Dr. G. Samuel Vara Prasada Raju received the M.Tech degree in CS&SE from Andhra University in 1993. He received PhD degree from Andhra University in 1996. From 1994 to 2003 worked as Asst. Professor in the Dept. of CS&SE in Andhra University College of Engineering. From 2003 onwards worked as Associate Professor and Director of the CS&SE Department for School of Distance Education of Andhra University College of Engineering. His research interest includes ecommerce, Network Security, Cryptography, Data Mining and parallel processing. He has more than 30 years of experience in Academics and Research.

Prof. Penmetsa V Krishna Raja has more than 15 years of academic experience. Presently he is working as Principal, AIMS college of Engineering, Amalapuram. He has Completed his Masters from Andhra University and Ph.d from JNTUK. He has published more than 20 research paper in reputed National and International Journals. His Research of interest includes Data Mining, Cryptography and Network Security, Bio Informatics, Image processing and Parallel processing.

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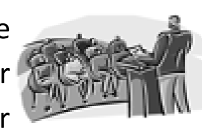

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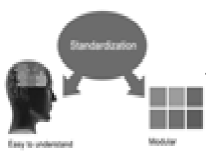

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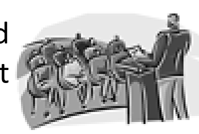

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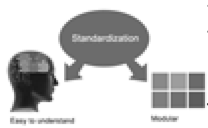

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Papers: These are reports of significant research (typically less than 7000 words equivalent, including tables, figures, references), and comprise:

(a)Title should be relevant and commensurate with the theme of the paper.

(b) A brief Summary, "Abstract" (less than 150 words) containing the major results and conclusions.

(c) Up to ten keywords, that precisely identifies the paper's subject, purpose, and focus.

(d) An Introduction, giving necessary background excluding subheadings; objectives must be clearly declared.

(e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition; sources of information must be given and numerical methods must be specified by reference, unless non-standard.

(f) Results should be presented concisely, by well-designed tables and/or figures; the same data may not be used in both; suitable statistical data should be given. All data must be obtained with attention to numerical detail in the planning stage. As reproduced design has been recognized to be important to experiments for a considerable time, the Editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned un-refereed;

(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

(h) Brief Acknowledgements.

(i) References in the proper form.

Authors should very cautiously consider the preparation of papers to ensure that they communicate efficiently. Papers are much more likely to be accepted, if they are cautiously designed and laid out, contain few or no errors, are summarizing, and be conventional to the approach and instructions. They will in addition, be published with much less delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and to make suggestions to improve briefness.

It is vital, that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

Format

Language: The language of publication is UK English. Authors, for whom English is a second language, must have their manuscript efficiently edited by an English-speaking person before submission to make sure that, the English is of high excellence. It is preferable, that manuscripts should be professionally edited.

Standard Usage, Abbreviations, and Units: Spelling and hyphenation should be conventional to The Concise Oxford English Dictionary. Statistics and measurements should at all times be given in figures, e.g. 16 min, except for when the number begins a sentence. When the number does not refer to a unit of measurement it should be spelt in full unless, it is 160 or greater.

Abbreviations supposed to be used carefully. The abbreviated name or expression is supposed to be cited in full at first usage, followed by the conventional abbreviation in parentheses.

Metric SI units are supposed to generally be used excluding where they conflict with current practice or are confusing. For illustration, 1.4 l rather than 1.4 × 10-3 m3, or 4 mm somewhat than 4 × 10-3 m. Chemical formula and solutions must identify the form used, e.g. anhydrous or hydrated, and the concentration must be in clearly defined units. Common species names should be followed by underlines at the first mention. For following use the generic name should be constricted to a single letter, if it is clear.

Structure

All manuscripts submitted to Global Journals Inc. (US), ought to include:

Title: The title page must carry an instructive title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) wherever the work was carried out. The full postal address in addition with the e-mail address of related author must be given. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining and indexing.

Abstract, used in Original Papers and Reviews:

Optimizing Abstract for Search Engines

Many researchers searching for information online will use search engines such as Google, Yahoo or similar. By optimizing your paper for search engines, you will amplify the chance of someone finding it. This in turn will make it more likely to be viewed and/or cited in a further work. Global Journals Inc. (US) have compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Key Words

A major linchpin in research work for the writing research paper is the keyword search, which one will employ to find both library and Internet resources.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy and planning a list of possible keywords and phrases to try.

Search engines for most searches, use Boolean searching, which is somewhat different from Internet searches. The Boolean search uses "operators," words (and, or, not, and near) that enable you to expand or narrow your affords. Tips for research paper while preparing research paper are very helpful guideline of research paper.

Choice of key words is first tool of tips to write research paper. Research paper writing is an art.A few tips for deciding as strategically as possible about keyword search:

- One should start brainstorming lists of possible keywords before even begin searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in research paper?" Then consider synonyms for the important words.
- It may take the discovery of only one relevant paper to let steer in the right keyword direction because in most databases, the keywords under which a research paper is abstracted are listed with the paper.
- One should avoid outdated words.

Keywords are the key that opens a door to research work sources. Keyword searching is an art in which researcher's skills are bound to improve with experience and time.

Numerical Methods: Numerical methods used should be clear and, where appropriate, supported by references.

Acknowledgements: Please make these as concise as possible.

References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

References to information on the World Wide Web can be given, but only if the information is available without charge to readers on an official site. Wikipedia and Similar websites are not allowed where anyone can change the information. Authors will be asked to make available electronic copies of the cited information for inclusion on the Global Journals Inc. (US) homepage at the judgment of the Editorial Board.

The Editorial Board and Global Journals Inc. (US) recommend that, citation of online-published papers and other material should be done via a DOI (digital object identifier). If an author cites anything, which does not have a DOI, they run the risk of the cited material not being noticeable.

The Editorial Board and Global Journals Inc. (US) recommend the use of a tool such as Reference Manager for reference management and formatting.

Tables, Figures and Figure Legends

Tables: Tables should be few in number, cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g. Table 4, a self-explanatory caption and be on a separate sheet. Vertical lines should not be used.

Figures: Figures are supposed to be submitted as separate files. Always take in a citation in the text for each figure using Arabic numbers, e.g. Fig. 4. Artwork must be submitted online in electronic form by e-mailing them.

Preparation of Electronic Figures for Publication

Even though low quality images are sufficient for review purposes, print publication requires high quality images to prevent the final product being blurred or fuzzy. Submit (or e-mail) EPS (line art) or TIFF (halftone/photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Do not use pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings) in relation to the imitation size. Please give the data for figures in black and white or submit a Color Work Agreement Form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution (at final image size) ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs) : >350 dpi; figures containing both halftone and line images: >650 dpi.

Figure Legends: Self-explanatory legends of all figures should be incorporated separately under the heading 'Legends to Figures'. In the full-text online edition of the journal, figure legends may possibly be truncated in abbreviated links to the full screen version. Therefore, the first 100 characters of any legend should notify the reader, about the key aspects of the figure.

6. AFTER ACCEPTANCE

Upon approval of a paper for publication, the manuscript will be forwarded to the dean, who is responsible for the publication of the Global Journals Inc. (US).

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The corresponding author will receive an e-mail alert containing a link to a website or will be attached. A working e-mail address must therefore be provided for the related author.

Acrobat Reader will be required in order to read this file. This software can be downloaded

(Free of charge) from the following website:

www.adobe.com/products/acrobat/readstep2.html. This will facilitate the file to be opened, read on screen, and printed out in order for any corrections to be added. Further instructions will be sent with the proof.

Proofs must be returned to the dean at dean@globaljournals.org within three days of receipt.

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Before start writing a good quality Computer Science Research Paper, let us first understand what is Computer Science Research Paper? So, Computer Science Research Paper is the paper which is written by professionals or scientists who are associated to Computer Science and Information Technology, or doing research study in these areas. If you are novel to this field then you can consult about this field from your supervisor or guide.

TECHNIQUES FOR WRITING A GOOD QUALITY RESEARCH PAPER:

1. Choosing the topic: In most cases, the topic is searched by the interest of author but it can be also suggested by the guides. You can have several topics and then you can judge that in which topic or subject you are finding yourself most comfortable. This can be done by asking several questions to yourself, like Will I be able to carry our search in this area? Will I find all necessary recourses to accomplish the search? Will I be able to find all information in this field area? If the answer of these types of questions will be "Yes" then you can choose that topic. In most of the cases, you may have to conduct the surveys and have to visit several places because this field is related to Computer Science and Information Technology. Also, you may have to do a lot of work to find all rise and falls regarding the various data of that subject. Sometimes, detailed information plays a vital role, instead of short information.

2. Evaluators are human: First thing to remember that evaluators are also human being. They are not only meant for rejecting a paper. They are here to evaluate your paper. So, present your Best.

3. Think Like Evaluators: If you are in a confusion or getting demotivated that your paper will be accepted by evaluators or not, then think and try to evaluate your paper like an Evaluator. Try to understand that what an evaluator wants in your research paper and automatically you will have your answer.

4. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

5. Ask your Guides: If you are having any difficulty in your research, then do not hesitate to share your difficulty to your guide (if you have any). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work then ask the supervisor to help you with the alternative. He might also provide you the list of essential readings.

6. Use of computer is recommended: As you are doing research in the field of Computer Science, then this point is quite obvious.

7. Use right software: Always use good quality software packages. If you are not capable to judge good software then you can lose quality of your paper unknowingly. There are various software programs available to help you, which you can get through Internet.

8. Use the Internet for help: An excellent start for your paper can be by using the Google. It is an excellent search engine, where you can have your doubts resolved. You may also read some answers for the frequent question how to write my research paper or find model research paper. From the internet library you can download books. If you have all required books make important reading selecting and analyzing the specified information. Then put together research paper sketch out.

9. Use and get big pictures: Always use encyclopedias, Wikipedia to get pictures so that you can go into the depth.

10. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right! It is a good habit, which helps to not to lose your continuity. You should always use bookmarks while searching on Internet also, which will make your search easier.

11. Revise what you wrote: When you write anything, always read it, summarize it and then finalize it.

12. Make all efforts: Make all efforts to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in introduction, that what is the need of a particular research paper. Polish your work by good skill of writing and always give an evaluator, what he wants.

13. Have backups: When you are going to do any important thing like making research paper, you should always have backup copies of it either in your computer or in paper. This will help you to not to lose any of your important.

14. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several and unnecessary diagrams will degrade the quality of your paper by creating "hotchpotch." So always, try to make and include those diagrams, which are made by your own to improve readability and understandability of your paper.

15. Use of direct quotes: When you do research relevant to literature, history or current affairs then use of quotes become essential but if study is relevant to science then use of quotes is not preferable.

16. Use proper verb tense: Use proper verb tenses in your paper. Use past tense, to present those events that happened. Use present tense to indicate events that are going on. Use future tense to indicate future happening events. Use of improper and wrong tenses will confuse the evaluator. Avoid the sentences that are incomplete.

17. Never use online paper: If you are getting any paper on Internet, then never use it as your research paper because it might be possible that evaluator has already seen it or maybe it is outdated version.

18. Pick a good study spot: To do your research studies always try to pick a spot, which is quiet. Every spot is not for studies. Spot that suits you choose it and proceed further.

19. Know what you know: Always try to know, what you know by making objectives. Else, you will be confused and cannot achieve your target.

20. Use good quality grammar: Always use a good quality grammar and use words that will throw positive impact on evaluator. Use of good quality grammar does not mean to use tough words, that for each word the evaluator has to go through dictionary. Do not start sentence with a conjunction. Do not fragment sentences. Eliminate one-word sentences. Ignore passive voice. Do not ever use a big word when a diminutive one would suffice. Verbs have to be in agreement with their subjects. Prepositions are not expressions to finish sentences with. It is incorrect to ever divide an infinitive. Avoid clichés like the disease. Also, always shun irritating alliteration. Use language that is simple and straight forward. put together a neat summary.

21. Arrangement of information: Each section of the main body should start with an opening sentence and there should be a changeover at the end of the section. Give only valid and powerful arguments to your topic. You may also maintain your arguments with records.

22. Never start in last minute: Always start at right time and give enough time to research work. Leaving everything to the last minute will degrade your paper and spoil your work.

23. Multitasking in research is not good: Doing several things at the same time proves bad habit in case of research activity. Research is an area, where everything has a particular time slot. Divide your research work in parts and do particular part in particular time slot.

24. Never copy others' work: Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

25. Take proper rest and food: No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

26. Go for seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

28. Make colleagues: Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

29. Think technically: Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

31. Adding unnecessary information: Do not add unnecessary information, like, I have used MS Excel to draw graph. Do not add irrelevant and inappropriate material. These all will create superfluous. Foreign terminology and phrases are not apropos. One should NEVER take a broad view. Analogy in script is like feathers on a snake. Not at all use a large word when a very small one would be sufficient. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Amplification is a billion times of inferior quality than sarcasm.

32. Never oversimplify everything: To add material in your research paper, never go for oversimplification. This will definitely irritate the evaluator. Be more or less specific. Also too, by no means, ever use rhythmic redundancies. Contractions aren't essential and shouldn't be there used. Comparisons are as terrible as clichés. Give up ampersands and abbreviations, and so on. Remove commas, that are, not necessary. Parenthetical words however should be together with this in commas. Understatement is all the time the complete best way to put onward earth-shaking thoughts. Give a detailed literary review.

33. Report concluded results: Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

34. After conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print to the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects in your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

Title Page:

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

Abstract:

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

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This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

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Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

Index

A

C

E

I

M

P

R

S

T

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