Nagarajan Ashokkumar[1], Marimuthu Rathinakumar, [2] Kannan Hari[3]

University of SCSVMV, EEE DEPT (1), University of SCSVMV, EEE DEPT (2), SS. Govt. Arts College, Thirutani (3)

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Path Analysis Model for Effective Load shedding

***Abstract**. In the present scenario, power system networks are operating very close to their limits. In order to prevent cascaded failures and eventually blackout, load shedding is used as a tool. There are many methodologies which discusses the effective ways for load shedding. In this work a new perspective is presented – path analysis. Path analysis is a technique under structured equation modelling which explains about dependent variable and independent variables. Here the output results are modelled and presented in path analysis, through which the significant variable which is crucial in determining the output can be identified. Correlation between crucial parameters which are having influence in output are also analysed.*

Streszczenie.** W zaprezentowanym scenariuszu system energetyczny pracuje blisko swoich granicznych możliwości. W celu zapobieżenia kaskadowej awarii lub blackoutu przewidziano możliwość odcinania obciążeń. Jako metodę zaproponowano algorytm analizy ścieżki (path analysis). Analizowano korelację między strategicznymi parametrami. **Model analizy ścieżki jako metoda skutecznej redukcji obciążeń system energetycznego

Keywords: blackout, cascaded failure, load shedding, path analysis
Słowa kluczowe: blackout, kaskadowa awaria, analiza ścieżki

Introduction

In recent years there are significant numbers of papers published in load shedding problem. Most of the works deal with a tool or technique used for shedding optimal value of load. Broadly these methods or techniques can be put under three categories.
1) Conventional load shedding- where under voltage load shedding and under frequency load shedding are important.
2) Adaptive load shedding
3) Computational techniques for load shedding.

Under computational techniques many types are there such as fuzzy logic control, neuro fuzzy, genetic algorithm and so on. (3).

From late 1980 and from start of 1990 the penetration of computational intelligence is felt in power systems and it has created a positive impact.

Artificial neural networks were deeply analysed by many researchers like Hooshmand.R et.al (4) and the results has significant improvement when compared to conventional techniques.

Similarly fuzzy logic has proved its flexibility and diligence in power system control problems, particularly in load shedding problems. Load shedding is used as a tool in present deregulated market, where most of the power system networks are operating very close to their limits.

If not properly done at the right time the network may eventually go for a cascaded failure.

Fuzzy logic is based on the mimic of human intelligence its solutions for load shedding problems are more optimized and also practical.

Research problem

In this work results from earlier works have been taken and it is applied over a new concept- path analysis. Path analysis even though it is widely used in other areas like sciences, management and so on, its potentiality is not fully explored in engineering, particularly in power systems.

Path analysis was originally developed by a geneticist Sewall Wright in 1920s to examine the effects of hypothesized models in phylogenetic studies. Here systems of equations were written by him based on correlations among variables. It is a statistical tool used primarily to examine the comparative strength of direct and indirect relationships among the variables (5). These variables are critical in influencing the output.

In this research three cases have been done with fuzzy logic as the fundamental technique. In the first work a real case example is analysed.

CASE I

The first case is enumerated below. The following table shows the data obtained from 220/110/11 KV substation.

The below table 1 clearly indicates the bus voltage values, reactive power, Pdiff and the load to shed. This is obtained from the classical load shedding formula given below.

$$S(\text{load to be shed}) = \frac{\left(\frac{dvi}{dqi}\right)}{\sum_{i=1}^{n}\left(\frac{dvi}{dqi}\right)} \text{ P diff}$$

Table 1. The values of V, Q, Pdiff & Load to Be Shed for 110 KV bus system

Voltage (KV)	Q (MVAR)	Pdiff (MW)	Load To be shed (MW)
101	49	9	3.18
101	49	18	18.59
103	51	3	6.13
103	29	33	14.09
104	45	27	17.19
104	50	24	17.19
105	39	24	10.32
105	39	17	10.59
106	45	30	11.43
106	30	39	28.19
106	59	35	15
107	40	39	21.20
107	44	18	8.29
107	54	3	2.64
108	45	27	5.71
109	34	27	0.448

(Table 1. from Reference 01)

Fuzzy memembership functions and rule sets are framed for these data and the overall results for 110kv bus and 220 KV bus is shown below, which indicates that the fuzy based load shedding is more good than the conventional load shedding(1).

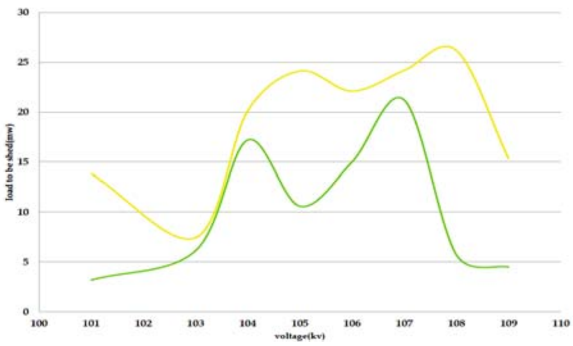

Fig.1.Compatrative Graph between conventional load shedding vs Fuzzy based load shedding for 110 KV bus system

Similarly for a 220 KV bus system the results are shown below

Table 2. Comparative Results between conventional method & Fuzzy system Approach (For 220 KV Bus)

Sl.No	Voltage KV	Load To be Shed (Conventional) MW	Load To be Shed Fuzzified MW
1.	199	14.72	0.705
2.	203	13.83	15.8
3.	205	20.12	16.6
4.	209	20.88	14
5.	211	24.18	23.31
6.	213	13.32	11.3
7.	215	26.37	18
8.	217	16.2	15.8

[Table 2 from Reference 01]

Similarly for 220 KV bus system the graph is shown below

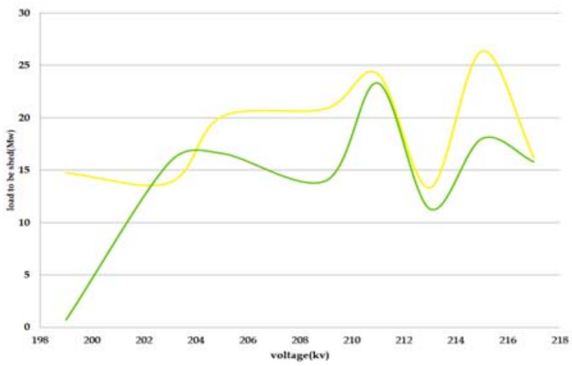

Fig.2.Compatrative Graph between conventional load shedding vs Fuzzy based load shedding for 220 KV bus system

These results are applied over path analysis and the following model was obtained. The basic theoritical model is given below. Where H1,H2,H3,H4,H5 represents regression coefficients. Also from the below model it is clear that the output(load to be shed) is dependent on voltage values, reactive power and also Pdiff. Where Pdiff is the difference in shaft power. Here Pdiff is used as the moderating variable. Through this research article it is been analysed how a path analysis can be effectively used to deeply understand how much critical is voltage,reactive power and Pdiff in deciding the value of load to be shed.

From this model it is observed that the input variables such as voltage, reactive power do not have significant impact on output(load to be shed).When the pdiff is used as moderator variable the impact on output is significant. The value of H5>0.5 it means its impact is more compared to other variables. In our case the value is 0.82. Here e1 and e2 are assigned correction factors in order to address the non-linear behaviour of power systems,because from classical equations it is clear that Pdiff is dependent on df/dt, which is highly non-linear. By assigning these correction factors e1 and e2 the accuracy of results are improved.

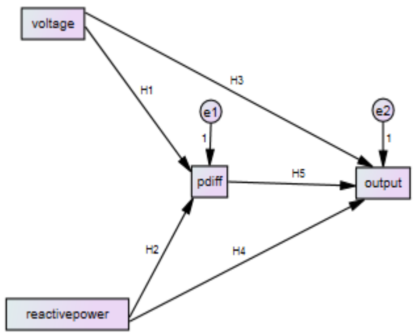

Fig.3.Theoritical Model of Path Analysis

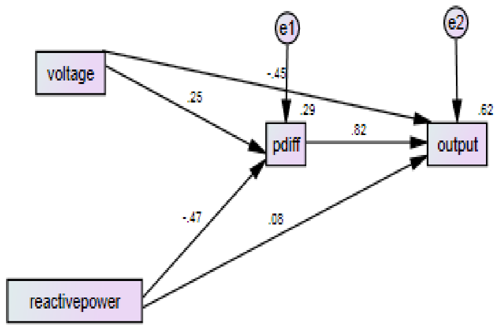

Fig.4.Practical Model of Path Analysis for Case I

The overall model fit summary is given below.

Model Fit Summary For Case I

CMIN

Model	NPAR	CMIN	DF	P	CMIN/ DF
Default model	9	.615	1	.433	.615
Saturated model	10	.000	0		
Independence model	4	20.660	6	.002	3.443

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	2.889	.980	.803	.098
Saturated model	.000	1.000		
Independence model	22.908	.679	.466	.408

BASELINE COMPARISONS

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.970	.821	1.020	1.158	1.000
Saturate model	1.000		1.000		1.000
Independen ce model	.000	.000	.000	.000	.000

PARSIMONY-ADJUSTED MEASURES

Model	PRATIO	PNFI	PCFI
Default model	.167	.162	.167
Saturated model	.000	.000	.000
Independence model	1.000	.000	.000

NCP

Model	NCP	LO 90	HI 90
Default model	.000	.000	5.869
Saturated model	.000	.000	.000
Independence model	14.660	4.440	32.449

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	.041	.000	.000	.391
Saturated model	.000	.000	.000	.000
Independence model	1.377	.977	.296	2.163

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.000	.000	.625	.442
Independence model	.404	.222	.600	.003

S.No	Voltage P.U	Reactive Power P.U	Frequency
1.	1.025	0.41	48.7
2.	1.020	0.15	48.5
3.	1.035	0.5	49.5
4.	1.050	0.1	49.2
5.	1.045	0.3	49.7
6.	0.999	0.29	48.5
7.	0.994	0	50
8.	0.997	0	50
9.	1.009	0.5	49.5
10.	0.989	0	50
11.	0.997	0.15	48.5
12.	0.993	0.48	48.7
13.	1.014	0.15	48.5
14.	1.000	0.12	48.5
15.	0.991	0.31	48.6
16.	0.983	0.27	48.5
17.	0.987	0.38	48.7
18.	1.007	0.67	48.7
19.	1.004	0.15	48.5
20.	0.980	0.27	48.7
21.	0.977	0.23	48.7
22.	0.978	0.22	49.7
23.	0.976	0.12	48.3
24.	0.968	0.27	49.7
25.	0.974	0.13	49.4
26.	1.015	0.2	49.8

AIC

Model	AIC	BCC	BIC	CAIC
Default model	18.615	27.615	25.568	34.568
Saturated model	20.000	30.000	27.726	37.726
Independence model	28.660	32.660	31.750	35.750

ECVI

Model	ECVI	LO 90	HI 90	MECVI
Default model	1.241	1.267	1.658	1.841
Saturated model	1.333	1.333	1.333	2.000
Independence model	1.911	1.229	3.097	2.177

HOELTER

Model	HOELTER 05	HOELTER 01
Default model	94	162
Independence model	10	13

Regression Weights: (Group number 1 - Default model)

			Esti mat	S.E.	C.R.	P	La bel
pdiff	<---	voltage	1.205	1.035	1.164	.244	
pdiff	<---	Reactive power	-.613	.282	-2.173	.030	
output	<---	pdiff	.561	.129	4.347	***	
output	<---	voltage	-1.462	.541	-2.705	.007	
output	<---	Reactive power	.072	.162	.442	.658	

From the model fit summary the CMIN/DF is 0.615 with the P value of 0.433 > 0.05 which indicates this model is free from bad fit index. Similarly the table RMSEA (Root Mean Square Error Approximation) shows the value 0.000 indicates the model is free from bad fit index. As far as good fitness of index is concerned the value belongs to 0.980 indicates the model has goodness of fit index.

From the estimate we can definitely conclude that reactive power has significant impact on Pdiff since the value is less than 0.05. In this case it is 0.03 < 0.05 (at 5% level of significance). It can be concluded that voltage has an impact on Pdiff. Similarly the impact on output with respect to Pdiff is also significant since the P value is *** **(**from final estimate table). *** indicates the results are highly authentic.

CASE II

In the second case the load sheddding technique using fuzzy logic is applied over classical IEEE 26 bus system and the crucial results are given below

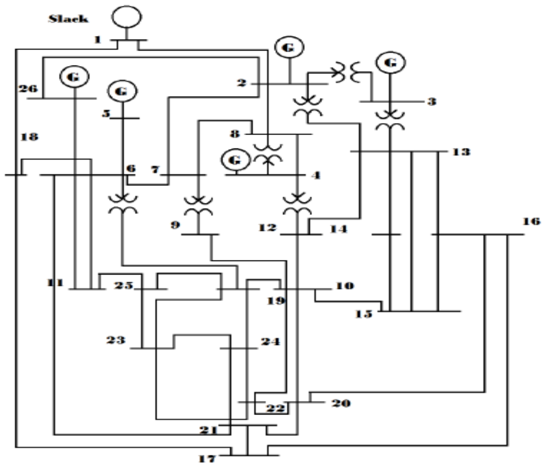

Fig.5. IEEE 26 bus system [Reference 02]

Table 3.The values of voltage, reactive power and frequency for IEEE 26 Bus System taken as example [Table 3 from Reference 02]

Table 4. Load to be shed by classical formula Pdiff

S.No	P_{diff} P.U	Load to Be shed P.U
1.	0.26	0.49
2.	0.31	0.32
3.	0.1	0.31
4.	0.16	0.39
5.	0.06	0.17
6.	0.31	0.02
7.	0	0
8.	0	0
9.	0.1	0.08
10.	0	0
11.	0.31	0.04
12.	0.26	0.15
13.	0.31	0.23

14.	0.31	0
15.	0.28	0.16
16.	0.31	0.32
17.	0.26	0.24
18.	0.26	0.24
19.	0.31	0.06
20.	0.35	0.42
21.	0.33	0.44
22.	0.37	0.46
23.	0.35	0.42
24.	0.35	0.68
25.	0.33	0.44
26.	0.04	0.03

[Table 4 from Reference 02]

These data are scaled by fuzzy logic and the final results are given below

Table 5.Comparative Results between conventional method & Fuzzy system Approach

S.No	Voltage P.U	Frequency Hz	Load to be Shed (Conventional)	Load to be shed (Fuzzified)
1.	1.025	48.7	0.49	0.4
2.	0.983	48.5	0.32	0.2
3.	0.978	48.7	0.46	0.3
4.	1.014	48.5	0.23	0.02
5.	0.968	48.7	0.68	0.4

[Table 5 from Reference 02]

These results are applied over path analysis and the following model was obtained.

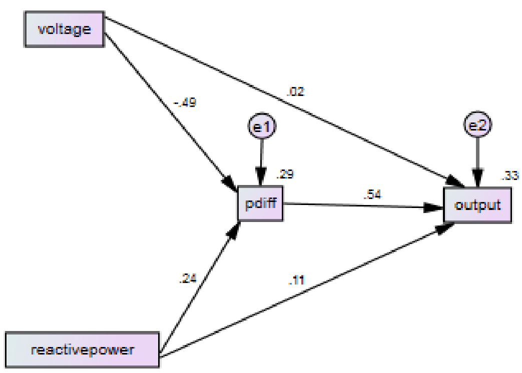

Fig.6. Practical Model of Path Analysis for Case II

Model Fit Summary for Case II

CMIN

Model	NPAR	CMIN	DF	P	CMIN/ DF
Default model	9	.736	1	.391	.736
Saturated model	10	.000	0		
Independence model	4	17.813	6	.007	2.969

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	.001	.986	.857	.099
Saturated model	.000	1.000		
Independence model	.005	.756	.594	.454

Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.959	.752	1.016	1.134	1.000
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

PARSIMONY-ADJUSTED MEASURES

Model	PRATIO	PNFI	PCFI
Default model	.167	.160	.167
Saturated model	.000	.000	.000
Independence model	1.000	.000	.000

NCP

Model	NCP	LO 90	HI 90
Default model	.000	.000	6.244
Saturated model	.000	.000	.000
Independence model	11.813	2.756	28.467

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	.029	.000	.000	.250
Saturated model	.000	.000	.000	.000
Independence model	.713	.473	.110	1.139

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.000	.000	.500	.406
Independence model	.281	.136	.436	.010

AIC

Model	AIC	BCC	BIC	CAIC
Default model	18.736	23.236	30.059	39.059
Saturated model	20.000	25.000	32.581	42.581
Independence model	25.813	27.813	30.845	34.845

ECVI

Model	ECVI	LO 90	HI 90	MECVI
Default model	.749	.760	1.010	.929
Saturated model	.800	.800	.800	1.000
Independence model	1.033	.670	1.699	1.113

HOELTER

Model	HOELTER 05	HOELTER 01
Default model	131	226
Independence model	18	24

Estimates

Regression Weights: (Group number 1 - Default model)

			Estimate	S.E.	C.R.	P	Label
pdiff	<---	voltage	-2.838	.978	-2.902	.004	H1
pdiff	<---	reactive power	.182	.128	1.419	.156	H2
output	<---	pdiff	.820	.296	2.767	.006	H5
output	<---	voltage	.148	1.676	.088	.930	H3
output	<---	reactive power	.133	.198	.674	.500	H4

From the model fit summary the CMIN/DF is 0.736 with the P value of 0.391 which is more than 0.05 (0.391>0.05) indicates this model is free from bad fit index.

Similarly the table RMSEA (Root mean square error approximation) shows the value is 0.000 indicates the model is free from bad fit index.

Table RMR,GFI indicates good fitness of index. As far as good fitness of index is concerned the value belongs to 0.986 indicates the model has goodness of fit index. From the overall table estimate we can definitely conclude that voltage has significant impact on Pdiff [since P value is less than 0.05, which indicates 5% level of coefficient]. From this it is concluded that voltage has an impact on Pdiff. Similarly the impact on output with respect to Pdiff is also significant since the P value is 0.006 which is less than 0.05 (5% level of significance).

CASE III

In the third case the rate of change of voltage (dv/dt) and the rate of change of reactive power (dq/dt) and its significance in the output (load to be shed) is analysed. This analysis is a crucial analysis in understanding the behaviour of load shedding. The third example is tested in IEEE -26 bus system as presented in the second case. The datas are from the second case example.

Table 6. Rate of change of voltage , Rate of change of reactive power and Rate of change of frequency.

Sl.No	dv/ dt	dq/ dt	df/ dt
1.	0.025	0.59	1.3
2.	0.02	0.85	1.5
3.	0.035	0.5	0.5
4.	0.05	0.9	0.8
5.	0.045	0.7	0.3
6.	0.001	0.71	1.5
7.	0.006	1	0
8.	0.003	1	0
9.	0.009	0.5	0.5
10.	0.011	1	0
11.	0.003	0.85	1.5
12.	0.007	0.52	1.3
13.	0.014	0.85	1.5
14.	0	0.88	1.5
15.	0.009	0.69	1.4
16.	0.017	0.73	1.5
17.	0.013	0.62	1.3
18.	0.007	0.33	1.3
19.	0.004	0.85	1.5
20.	0.020	0.73	1.3
21.	0.023	0.77	1.3
22.	0.022	0.78	1.3
23.	0.024	0.88	0.7
24.	0.032	0.73	1.3
25.	0.026	0.87	0.6
26.	0.015	0.8	0.2

[Table 6. from Reference 02]

This is applied over path analysis and the model fit is as presented below.

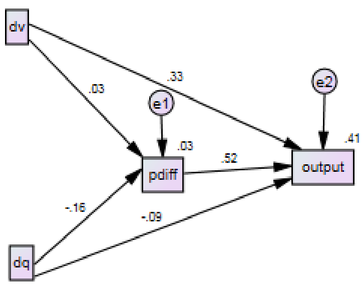

Fig.7. Practical Model of Path Analysis for Case III

From this model it is observed that the input variables such as change of voltage, change of reactive power have impact on output(load to be shed) but relatively less when compared with the pdiff which is used as moderator variable then the impact on output is significant. Here e1 and e2 are assigned correction factors in order to address the non-linear behaviour of power systems,because from classical equations it is clear that Pdiff is dependent on df/dt, which is highly non-linear. By assigning these correction factors e1 and e2 the accuracy of results are improved.

The overall model fit summary is given below.

Model Fit Summary for Case III

CMIN

Model	NPAR	CMIN	DF	P	CMIN/ DF
Default model	9	.258	1	.612	.258
Saturated model	10	.000	0		
Independence model	4	14.411	6	.025	2.402

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	.000	.995	.949	.099
Saturated model	.000	1.000		
Independence model	.005	.798	.664	.479

BASELINE COMPARISONS

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.982	.893	1.055	1.530	1.000
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

PARSIMONY-ADJUSTED MEASURES

Model	PRATIO	PNFI	PCFI
Default model	.167	.164	.167
Saturated model	.000	.000	.000
Independence model	1.000	.000	.000

NCP

Model	NCP	LO 90	HI 90
Default model	.000	.000	4.457
Saturated model	.000	.000	.000
Independence model	8.411	.902	23.565

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	.010	.000	.000	.178
Saturated model	.000	.000	.000	.000
Independence model	.576	.336	.036	.943

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.000	.000	.422	.623
Independence model	.237	.078	.396	.035

AIC

Model	AIC	BCC	BIC	CAIC
Default model	18.258	22.758	29.581	38.581
Saturated model	20.000	25.000	32.581	42.581
Independence model	22.411	24.411	27.444	31.444

ECVI

Model	ECVI	LO 90	HI 90	MECVI
Default model	.730	.760	.938	.910
Saturated model	.800	.800	.800	1.000
Independence model	.896	.596	1.503	.976

HOELTER

Model	HOELTER .05	HOELTER .01
Default model	373	644
Independence model	22	30

Regression Weights: (Group number 1 - Default model)

			Estimate	S.E.	C.R.	P	Label
pdiff	<---	dv	.184	1.202	.153	.878	
pdiff	<---	dq	-.116	.148	-.787	.431	
output	<---	dv	3.038	1.426	2.131	.033	
output	<---	dq	-.102	.177	-.576	.565	
output	<---	pdiff	.792	.237	3.341	***	

From the model fit summary the CMIN/DF is 0.258 with the P value of 0.612 which is more than 0.05 (0.612>0.05) indicates this model is free from bad fit index.Similarly the table RMSEA (Root mean square error approximation) shows the value is 0.000 indicates the model is free from bad fit index. Table RMR,GFI indicates good fitness of index. As far as good fitness of index is concerned the value belongs to 0.995 indicates the model has goodness of fit index. From the overall table estimate we can definitely conclude that change of voltage has significant impact on output [since P value is less than 0.05, which indicates 5% level of coefficient]. In this case it is 0.03 < 0.05 . also it can be concluded that Pdiff has a very strong impact on output – load to be shed. since the value is ***. It proves the authenticity of results.

Conclusion

Path analysis is a very useful as well as powerful tool to understand the behaviour of any system. In engineering, particulary in power system engineering the tool is seldom applied.In this work the tool is applied for fuzzy based load sheddding problems, and the authenticity of the results are verified. Moreover three cases have been taken from earlier works of the authors and path fit summary (path analysis) was done. The results of all the three cases exhibits goodness of fit (GFI). It can be reiterated that Pdiff(difference in power) is very crucial in deciding the amount of load to be shed.

Further the application of this tool can be critically explored in power systems prolems.

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Authors: *N.Ashok kumar, Assistant Professor, University of SCSVMV, Enathur, Kanchipuram, Tamil Nadu, Email: nr.ashokk@gmail.com; Dr.M.Rathina kumar, Professor, University of SCSVMV, Enathur, Kanchipuram, Tamil Nadu, Email: rathinamari@rediffmail.com; Dr.K.Hari, Assistant Professor, Sri Subramaniya Swamy Government Arts College, Thirutani, Tamil Nadu, Email: kha_2k@yahoo.co.in.*