ISSN 2229-5518

Available Transfer Capability Calculations with Contingencies for Andhra Pradesh State Grid

Chava Sunil Kumar, Dr. P. S Subramanyan, Dr. J. Amarnath

Abstract— Contingency analysis and risk management are important tasks for the safe operation of electrical energy network. Potential harmful disturbances that occur during the steady state operation of a power system are known as contingencies. Contingency analysis is carried out by using repeated load flow solutions for each of a list of potential component failures. In this paper is work is carried out by selecting the contingencies according to the line loading for single transmission line outage and identified the severe most contingency based on transmission line loading. This process has to be executed for all the possible contingencies for tie lines and limiting lines, and repeated every time when the structure changes significantly and Available Transfer Capability (ATC) is calculated between the areas for each contingency. The results are analyzed and discussed on 124-bus real life Indian utility system of Andhra Pradesh State Grid.

Index Terms— Contingency, ATC, Outage, MVA rating, Blackout.

---

1 Introduction

ONE of the most important factors in the operation of a power system is the desire to maintain system security. System security involves practices designed to keep the system operating when components fail. For example, a generating unit may have to be taken off-line because of auxiliary equipment failure. By maintaining proper amounts of spinning reverse, the remaining units on the system can make up the deficit without too low a frequency drop or need to shed any load. Similarly, a transmission line may be damaged by a storm and taken out by automatic relaying. If, in committing and dispatching generation, proper regard for transmission flows is maintained, the remaining transmission lines can take the increased loading and still remain within limit. Because the specific times at which initiating events that cause components to fail are unpredictable, the system must be operated at all times in such a way that the system will not be left in a dangerous condition should any credible initiating event occur. Since power system equipment is designed to be operated within certain limits, most pieces of equipment are protected by automatic devices that can cause equipment to be switched out of the system if these limits are violated. If any event occurs on a system that leaves it opening with limits violated, the event may be followed by a series of cascading failures continues, the entire system or large parts of it may completely collapse. This is usually referred to as a system blackout [1].
An example of the type of event sequence that can cause a blackout might start with a single line being opened due to an insulation failure; the remaining transmission circuits in the system will take up the flow that was flowing on the now-opened line. If one of the remaining lines is now heavily loaded, it may open due to relay action, thereby causing even more load on the remaining lines. This type of process is often termed a cascading outage. Most power systems are operated such that any single initial failure event will not leave other components heavily overloaded, specifically to avoid cascading failures.

Contingency Analysis (CA), as a part of static security analysis, is critical in many routine power system and power market analysis, such as ATC evaluation, security assessment and transaction arrangement. A typical CA has models, single element outage (one –transmission line, one generator outage, etc.), multiple element-outages (two-transmission line outage, one –transmission line and one generator outage, etc.) and sequential outage (one outage after another) [3]. In the case of loss of one component, this corresponds to the N − 1 criterion, i.e. the system should be able to support the load when one of the N basic transmission system components (transmission lines, generators or transformers) is out of operation. The application of the criterion can also be extended for the case of loss of combinations of these basic components. When applied to the loss of two components, it leads to the N – 2 criterion. Since a contingency can take place at any instant of operation, the system design should be such that the system is able to deal with the worst-case scenario, i.e. the peak load. Limit checking is done for each contingency to determine whether the system is secure [4].

With the global towards the deregulation in the power system industry, the volume and complexity of the CA results in the operation and the system studies have been increasing. Not only has deregulation resulted in much larger system model sizes, but also CA is computed more frequently in the restructured power markets to monitor the states of the system under “what if” situations in order to accommodate the maximum number of power transfers. The net impact of these changes is a need for more effective CA results are required to help with the comprehension of the essential security information, information which could be buried in the enormous and complex CA data sets [7], [8].

A 124-bus real life Indian Utility system is considered to find the variation of ATC between the areas for transmission line outage of tie-lines. Contingency ranking is taken according to the percentage loading of the lines.

ISSN 2229-5518

2 Background of ATC

The Available Transfer Capability (ATC) problem is the determination of the largest additional amount of the power above some base case value that can be transferred in a prescribed manner between two sets of buses; the source, in which power injections are increase, and the sink, in which power injections are decreased by an offsetting amount. Increasing the transfer power increases the loading in the network, and at the same point causes an operational or physical limit to be reached that prevents the further increase. Limitations checked for the base case are: normal branch flow limits, generator limits, bus voltage limits and stability limits.

The ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above previously committed uses. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM) and the Capacity Benefit Margin (CBM) [11]-[13].

$$\therefore ATC = TTC - TRM - CBM \quad (1)$$

TTC is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre and post-contingency system conditions.

TRM is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

CBM is defined as that amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.

3 Contingency Analysis

The CA application is based on detailed electrical model of power system, called the "network model". This is a simulated model of the real power system that is prepared by each utility's system planners and network engineer specialists. They translate the real world equipment and connections of a power system (one –line diagram) into a mathematical model of the power network that is suitable for solution by computer algorithms. This network model contains the connection information and electrical characteristics of the equipment. The algorithm in contingency analysis uses this network information and the network model to simulate, and calculate the effects of, removing equipment from the power system [2]. With an initialized power network model, CA now can be executed with a series of contingency events that is prepared by the CA user. A "Contingency List" contains the each of the elements that will be removed from the network model, one by one, to test the effects for possible overloads of the remaining elements. The criteria for selection of elements for the contingency events are further described below.

In its basic form, CA executes a power flow analysis for each potential problem that is identified on a contingency list. The voltages, currents, real and reactive power flows (MW and Mvar) in each part of the power system can be obtained from power flow solution in contingency analysis. Results of each contingency test and the network solution are compared with the limits for every element in the power system. The lists of violations are saved in the CA data base.

Contingency Analysis actually provides and prioritizes the impacts on an electric power system when problems occur. Contingency is also called an unplanned "outage". Contingency analysis is a computer application that uses a simulated model of the power system, to evaluate the effects, and calculate any overloads resulting from each outage event. In other word, Contingency Analysis is essentially a "preview" analysis tool that simulates and quantifies the results of problems that could occur in the power system in the immediate future. This Analysis is used as a study tool for the off-line analysis of contingency events, and as an on-line tool to show operators what would be the effects of future outages. It allows operators to be better prepared to react to outages by using pre-planned recovery scenarios [5], [6].

After a contingency event, power system problems can range from:

• None: When the power system can be re-balanced after a contingency, without overloads to any element.

• Severe: When several elements such as lines and transformers become overloaded and have risk of damage.

• Critical: When the power system becomes unstable and will quickly collapse.

By analyzing the effects of contingency events in advance, problems and unstable situations can be identified, critical configurations can be recognized, operating constraints and limits can be applied, and corrective actions can be planned.

4 Case Study of 124-bus Indian Utility system

In a competitive electricity market, there will be many market players such as generating companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs), and system operator (SO). Similarly Andhra Pradesh State Electricity Board (APSEB) is divided into Andhra Pradesh Generating Company (APGENCO), Andhra Pradesh Transmission Company (APTRANCO) and Andhra Pradesh Distribution Company (APDISCO). All are operating as independent companies under the government of Andhra Pradesh. APDISCO is again divided into four companies as Northern Power Distribution Company Limited (NPDCL), Central Power Distribution Company Limited (CPDCL), Eastern Power Distribution Company Limited (EPDCL), and Sothern Power Distribution Company Limited (SPDCL). Each Distribution Company is considered as one area for this analysis.

At present APGENCO is operating with Installed Capacity of 8923.86 MW (Thermal 5092.50MW and 3831.36MW) along with Private sector of 3286.30MW and Central Generating Stations (CGS) share of 3209.15MW. A 124-bus Indian utility real-life power system at 220kV is used for portfolio analysis in different operating scenarios. The details of Areas and Total Generation, Load, Losses, and Cost of Generation are given in Table 1 and 2.

TABLE 1. DETAILS OF AREA WISE BUSES

Area No.	Area Name	Buses Number (Total No. of Buses)
1	NPDCL	1-5,12,24,26,27,29,30-35,37,38,129 (19)
2	CPDCL	6-11,13,15-23,25,28,36,39-54, 56-65,121,124,128 (48)
3	EPDCL	93,95-118,123 (26)
4	SPDCL	55,66-75,77-92,94,120,125,126 (31)

TABLE 2. DETAILS OF TOTAL GENERATION, LOAD, LOSSES, AND COST OF GENERATION

Total Generation (MW)	10587.61
Total Load(MW)	10366.00
Total Losses(MW)	221.60
Cost of Generation (Rs./Hr.)	20701659.61

For this analysis, tie-line MVA Loading is considered for ranking. Contingency Ranking of all the tie-lines is given in Table 3. Out of all these line outages, line 57-72 outage is more severe and causes system blackout. Outage of lines 1-28 and 37-28, isolate the Area 1 from the remaining system, calculation of ATC is Not Existing (NE). Outage of line 54-84 causes the overloading of the 54-46 by 16% due to that ATC from Area 2 to remaining Areas becomes negative. Variation of the ATC between the Ares is given in the Tables 4 and 5.
ATC calculations are extended for the some of the limiting lines also and all these lines are loaded in between 60 – 70%. Outage of lines 49-46 is more sever, causes system blackout. The details of varitation of ATC for these lines are given in Table 6.

Amongst deterministic security criteria, the most generally used is certainly the N-1 criterion. Indeed it corresponds to possible events. This criterion stipulates amongst other things that in its state N, that is to say when all elements of the system are in operation, operating conditions are in accordance with rules. Generally this is tested for different conventional states at least for peak and off peak load of the system etc. It implies further that for all types of incidents leading to the disconnection of only one element (generator, line, transformer, etc) the system operating point stays within the requested area. The operating point and the system is then declared N-1 secure. To find secured operating of the system the above given ATC numbers are more useful of the operators of the Andhra Pradesh State Electricity Market [9].

TABLE 3. CONTINGENCY RANKING OF TIE-LINES

From Bus	From Bus Name	To Bus	Name	Circuit	MW	Mvar	MVA Rating	%MVA Loading	Contingency Rank
40	CHK	84	TPL	1	-217.1	3.3	400	55.1	1
1	RSS	28	NGRM	2	-189.8	35	400	48.2	2
1	RSS	28	NGRM	1	-189.8	35	400	48.2	
46	SSM	82	PDL	1	183.1	-27.5	400	47.4	3
30	KTS	19	SHN	1	174.4	8.7	400	43.6	4
57	ATP	72	RTP	2	-169.3	-19.4	400	42.6	5
57	ATP	72	RTP	1	-169.3	-19.4	400	42.6	
35	BPD	42	BHN	1	163.3	2.4	400	42.3	6
46	SSM	120	MKP	1	165.6	-12.3	400	41.5	7
27	OGLP	28	NGRM	2	150	-7.8	400	37.6	8
27	OGLP	28	NGRM	1	150	-7.8	400	37.6	
12	KMD	11	GJWL	1	-149	-4.6	400	37.3	9
30	KTS	87	NUN	1	138.6	38.4	400	35.9	10
54	NSR	84	TPL	3	92.2	-11	525	35.5	11

54	NSR	84	TPL	2	184.3	-22	525	35.5	
54	NSR	84	TPL	1	184.3	-22	525	35.5	
38	WKP	42	BHN	1	119.2	-9.4	400	29.9	12
95	BMD	85	VTS	1	108.3	-32.8	400	28.2	13
95	BMD	87	NUN	1	90.1	-31.2	400	23.7	14
39	NKP	89	CLK	2	-93.1	9.2	400	23.4	15
39	NKP	89	CLK	1	-93.1	9.2	400	23.4	
46	SSM	55	MYD	1	79.8	-23.3	400	20.8	16
30	KTS	36	MGD	1	73.9	19.1	400	20.7	17
31	LSL	113	DNK	1	-49.4	8.2	400	19.4	18
35	BPD	36	MGD	1	45.6	51.8	400	19.4	19
31	LSL	101	BMR	1	73.2	-7.2	400	19.1	20
99	KVK	85	VTS	1	53.8	-12.1	400	15	21
93	BVRM	92	GDV	2	56.3	-9.5	400	14.8	
93	BVRM	92	GDV	1	56.3	-9.5	400	14.8	22
37	WGL	28	NGRM	2	40.2	-26.9	400	12.5	
37	WGL	28	NGRM	1	40.3	-29.6	400	12.5	23
24	DSD	25	SDP	2	48.2	-2.8	400	12.1	
24	DSD	25	SDP	1	48.2	-2.8	400	12.1	24
124	KDR	69	RJP	1	-18	26.7	400	8.1	25
124	KDR	71	RNG	1	7.9	-12.7	400	4.3	26
46	SSM	84	TPL	2	9.7	6.2	400	3.2	27
46	SSM	84	TPL	1	9.7	6.2	400	3.2	

TABLE 4. ATC BETWEEN AREAS WITH CONTINGENCIES

Transfer Areas	Bas Case	Contingency Line												
		40-84	1-28	46-82	30-19	57-72	35-42	46-120	27-28	12-11	30-87	54-84	38-42	95-85
	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)
1-2	2061	1873	NE	1346	1736	System Blackout	1563	1368	1518	2217	1730	2054	1720	2010
1-3	1040	1086	NE	1019	947		976	1023	1101	1128	785	1048	992	1017

ISSN 2229-5518

1-4	838	834	NE	754	841	844	770	852	848	814	807	842	835
2-1	681	675	NE	630	737	728	640	524	540	682	-66	705	691
2-3	1355	971	1286	1145	1350	1376	915	1017	1075	1367	-29	1408	1286
2-4	1408	1408	1408	1408	1406	1408	1162	1404	1408	1408	-118	1408	1408
3-1	1146	1146	NE	1146	1146	1146	1146	1079	802	1136	1146	1146	1141
3-2	1299	1288	1323	1341	1296	1284	1334	1269	1255	1325	1296	1294	1203
3-4	869	856	845	795	877	874	808	882	880	857	837	872	830
4-1	676	676	NE	676	676	676	676	676	676	676	676	676	676
4-2	2576	2580	2587	2577	2578	2593	2581	2573	2723	2574	2597	2583	2577
4-3	675	675	675	675	675	676	675	675	675	676	675	675	675

TABLE 5. ATC BETWEEN AREAS WITH CONTINGENCIES

Transfer Areas	Contingency Line												
	95-87	39-89	46-55	30-36	31-113	35-36	31-101	99-85	93-92	37-28	124-69	124-71	46-84
	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)
1-2	1997	2235	1156	1895	2033	1854	1756	2028	1959	NE	2056	2036	2043
1-3	1021	1068	1037	1014	917	1007	768	1023	1020	NE	1040	1040	1040
1-4	637	851	473	843	838	844	805	837	836	NE	836	831	845
2-1	687	590	675	663	652	900	665	686	693	NE	680	681	720
2-3	1322	1287	1343	1362	1383	1408	1374	1312	1303	1408	1353	1353	1379
2-4	1408	1408	1362	1408	1408	1408	1408	1408	1408	1408	1408	1408	1408
3-1	1022	1090	1146	1146	1146	1146	1080	1146	742	NE	1146	1146	1146
3-2	1087	1246	1169	1296	1249	1294	1346	1257	954	1281	1296	1303	1287
3-4	713	897	493	873	872	872	871	867	723	864	865	860	878
4-1	676	676	676	676	676	676	676	676	676	NE	676	676	676
4-2	2577	2495	2577	2576	2576	2581	2576	2577	2577	2578	2576	3577	2582
4-3	675	676	675	675	676	675	676	675	675	675	675	675	675

TABLE 6. ATC BETWEEN THE ARES FOR OTHER LIMITING LINES

Transfer Areas	Bas Case	Contingency Line							
		49-46	102-115	21-47	29-35	100-101	42-35	54-46	97-98

	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)	ATC (MW)
1-2	2061	System Blackout	2052	1343	1269	2086	1563	2048	2048
1-3	1040		992	1147	562	1063	978	1040	1042
1-4	838		838	771	441	838	844	843	837
2-1	681		681	132	297	672	728	690	685
2-3	1355		1356	237	719	1366	1376	1388	1352
2-4	1408		1408	504	1312	1408	1408	1408	1408
3-1	1146		1146	300	506	487	1146	1146	1044
3-2	1299		1238	1344	1347	795	1284	1293	1143
3-4	869		869	790	909	521	874	874	804
4-1	676		676	179	370	676	676	676	676
4-2	2576		2576	2581	2364	2577	2593	2579	2577
4-3	675		675	446	675	675	675	675	675

5 Conclusion

From economic considerations, sometimes the regional grid has to be operated even under non-compliance of N-1 security criterion. Under such conditions only automation (System Protection Scheme) can come to rescue the grid. However in the absence of System Protection Scheme (SPS), load shedding & rapid backing down of generation is the means to tide over the contingencies to meet the real time requirements. The operator requires lookup tables which indicate remedial action for potentially hazarder's contingencies [10]. The off -line studies can also be used to prepare look up tables and would become most important in case of failure of State Estimator (SE) to converge. Further the offline studies would also help user to select user defined contingencies for the online application such as Real Time Contingency Analysis (RTCA). After running RTCA the SE outputs for those potentially hazardous cases can be saved as "saved cases" and more detailed studies can be carried out in "study mode". The saved case can also be transferred to Power System simulator Engine (PSS/E) for carrying out dynamic studies as these are not available in EMS. Carrying out dynamics in off-line mode is important as stability limits would help in identifying limits, reliability margin etc.

Acknowledgements

The authors are thankful to the management of CVR College of Engineering, Ibrahimpatnam, R.R District and JNT University, Hyderabad, for providing facilities and to publish this work.

References

[1] A.J. Wood, B.F. Wollenberg, *Power Generation, operation and control*. New York: John Wiley & Sons, 1996, pp. 411-450.

[2] C.N. Lu, M. Unum, "Interactive Simulation of Branch Outages with Remedial Action on a Personal Computer for the Study of Security Analysis," *IEEE Trans. Power Systems*, Vol. 6, No. 3, pp. 1266-1271, Aug. 1991.

[3] Ming Ni, J.D. McCalley, V. Vittal, S. Greene, Chee-Wooi Ten, V. Sudhakar, T. Tayyib, "Software Implementation of Online Risk-based Security Assessment," *IEEE Trans. Power System*., Vol. 18, No. 3, pp.1165-1172, Aug. 2003.

[4] Ismail Musirin and Titik Khawa Abdul Rahnian – "Fast Automatic Contingency Analysis and Ranking technique for Power System Security Assessment"; *Proceedings Student conference on research and development (SCOReD)*, Putrajaya, Malaysia, 2003.

[5] Anant Oonsivilai and Kenedy A. Greyson – "Power System Contingency Analysis Using Multiagent Systems"; World Academy of Science, Engineering and Technology 60 2009.

[6] Arfita Yuana Dewi, Sasongko Pramono Hadi, Soedjatmiko – "Contingency Analysis of Power System Electrical Operation"; *Proceedings of the International Conference on Electrical Engineering and Informatics Institute,* Teknologi Bandung, Indonesia June 17-19, 2007.

[7] Quirino Morante, Nadia Ranaldo, Alfredo Vaccaro, Member, IEEE, and Eugenio Zimeo – "Pervasive Grid for Large-Scale Power Systems Contingency Analysis"; IEEE *Transactions on Industrial Informatics,* Vol. 2, No. 3, August 2006.

[8] Sun, Y., and Overbye, T.J. "Three Dimensional Visualizations for Power System Contingency Analysis Voltage Data", *Proceedings of the 6th International Conference on Advances in Power System Control, Operation and Management*, Hong Kong. 2003

[9] P. Pentayya, P. Mukopadhyay, S. Banerjee, M.K. Thakur, "Contingency Analysis for Eastern Reginal Grid of India", *16th National Power Systems Conference*, pp. 359-363, 2010.

[10] M.G.Raoot, P.Pentayya and S.Ganguly, "Evaluation of Potential Threats to Grid Security by Contingency Analysis in WRLDC, Mumbai", *National Power System Conference (NPSC)*, DEC.2008.

[11] NERC Operating Manual (latest edition), available at http:*www.nerc.com*.

[12] Transmission Transfer Capability Task Force, Transmission Transfer Capability, North American Electric Reliability Council, Princeton, New Jersey, May 1995.

[13] Transmission Transfer Capability Task Force, Available Transfer

Capability Definitions and Determination, North American Electric Reliability Council, Princeton, New Jersey, June 1996.

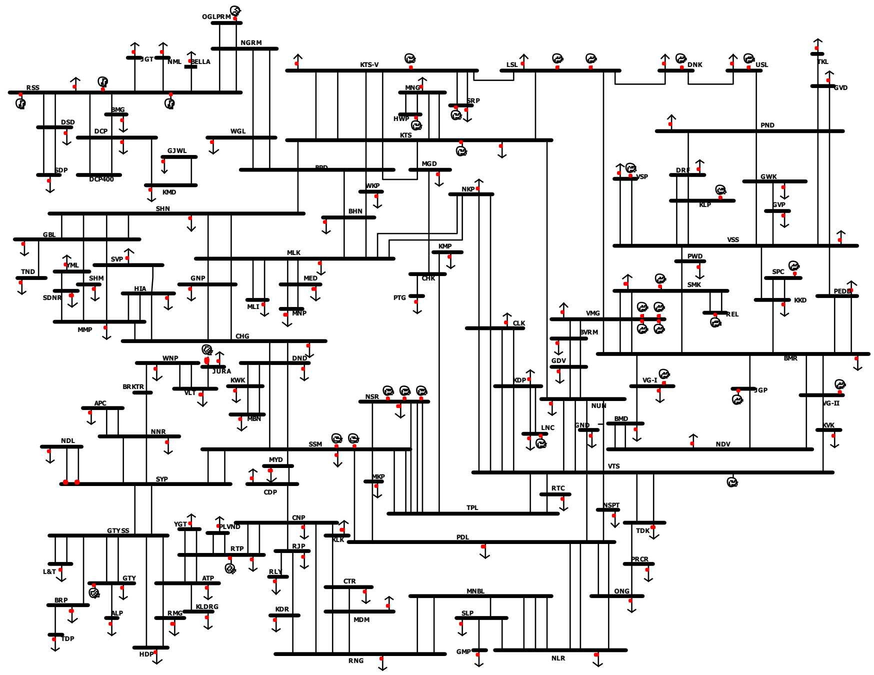

Fig 1. 124-Bus Indian utility real-life Power System of Andhra Pradesh State Grid

Chava Sunil Kumar born in khammam on February 25, 1977 received B Tech degree in electrical and electronics engineering in the year 2000 and M Tech degree in Electrical Power Engineering the year 2006 from JNTU College of Engineering, Kukatpally, Hyderabad, AP, India. He currently pursuing Ph.D. in Electrical Engineering from JNTU, Hyderabad and Working as Associate Professor in CVR College of Engineering, Hyderabad.
His area of interest includes Electrical Power systems, Power electronics and Electrical Machines.
Mr. Chava is life member of Indian Society for Technical Education (ISTE).

J. Amarnath obtained the B.E degree in electrical engineering from Osmania University, Hyderabad, A.P. India in 1982 and the M.E. degree in power systems from Andhra University, Visakhapatnam in1984. He worked in Tata Electric Company, Bombay during 1985-1986. In 1987 he was a Lecturer in Andhra University for a period of 2 years and then he joined in Nagarjuna University for a period of 4 years as Lecturer. In 1992 he joined JNTU College of Engineering, Kukatpally, Hyderabad. Presently he is professor in the department of Electrical and Electronics engineering department, JNTU, Hyderabad, A.P.

He presented more than 250 research papers in national and international conferences. His research interests includes high voltage engineering, gas insulated substations, industrial drives, power electronics, power systems, microprocessors and microcontroller applications to power systems and industrial drives.
Dr. Amarnath is life member of Indian Society for Technical Education (ISTE).

P S Subrahmanian received his bachelor of technology in Electrical & Electronics Engineering In the year 1960 & Masters Degree in Electrical Engineering from Jawaharlal Nehru Technological University in the year 1977. He received his PhD from IIT Madras in the year 1983. He Presently Working as Professor and Head in Department of EEE at VBIT, Hyderabad.
He published a number of papers in National and International Journals and several text books. Basically from Electrical Engineering discipline, he crosses migrated to the field of Computer Science and Engineering. His areas of interest include Fault analysis & diagnosis of six phase system & six phase induction motors.
Dr. Pasupati sadasiva fellow of The Institution of Engineers (India), fellow of National Federation of Engineers, Senior Member of IEEE, Member of Computer Society of India, Member of Indian Society for Technical Education.