Semiconductor Optoelectronics, *Vol. 42 No. 2 (2023), 415-423*
https://bdtgd.cn/

Semiconductor Optoelectronics
ISSN:
1001-5868

EFFECT ANALYSIS AND MODELLING OF AC LOSS OF SUPERCONDUCTING MAGNET A CONCEPTUAL APPROACH

[1*]Gladya Anusha.A, [2]Dr.S. AjinSundar,

[1] Research Scholar(Full time) Reg.No: 20113232132004, Department of Physics, St. Jude's College, Thoothoor-629176. Affiliated to Manonmaniam Sundaranar University Tirunelveli 627012, Tamilnadu, India

[2] Assistant professor, Department of Physics, St. Jude's College, Thoothoor-629176. Affiliated to Manonmaniam Sundaranar University Tirunelveli- 627012, Tamilnadu, India

[1*]gladyaanusha@gmail.com

Abstract:
The modelling of a superconducting magnet is discussed in this paper utilising finite element methods to analyse the AC losses involved. Because there are numerous ways for calculating AC losses in superconducting tapes, the approach utilised in this work was chosen based on the correctness of the answer and the computational time required. Following the presentation of the magnet's computational domain, the Maxwell's equations are solved using the ComsolMultiphysics software tool for 2D models utilising H-formulations. To decrease computational time, assumptions are used to describe the coil cross-section as a series of discrete turns. To boost accuracy and computing speed even further, mapped meshing is used to mesh the computational domain. To determine the critical current density, the Kim model was used to account for local fluctuations in the magnetic field. During the inquiry, numerous interesting topics for additional examination are discovered, and a comprehensive modelling of the stacked superconducting tapes is completed.

Keywords: H-formulations, Kim-model, Comsol MultiPhysics, AC Losses, Superconducting magnet, Maxwell equations

AC Losses in HTS conductors:

Most electric power applications have discovered that resistance emerges in type II superconductors due to flux flow and flux creep at low frequencies. In the presence of a greater magnetic field, type II superconductors may carry more current. However, losses in type II superconductors may occur due to the development of an electric field. Next-generation superconductors will replace conventional conductors because the former create negligible losses when compared to the latter. However, before they can be used in real-world applications, superconductors must meet a number of criteria, including a high critical current and a cheap price. Because superconducting devices operate at extremely low temperatures (almost 77 K), economic considerations must be taken into account when maintaining such low temperatures. Moreover, Heat generated by AC losses adds to the overall cost of the system because this heating load must be balanced by the cryogenic unit.

As a result, before introducing superconductors into power devices, financial restrictions like as material cost, energy cost, cryogenic unit cost, maintenance cost, and system dependability must be considered. Because superconductor resistance is almost minimal when compared to normal conductor resistance, AC losses are found to be smaller in superconducting systems than in ordinary systems. As a result, it is critical to properly calculate the AC losses in order to cheaply remove the heat load from the system while maintaining the system's superconductivity. There are two methods for cooling: convection cooling and conduction cooling. Heat dissipation in convective cooling can be accomplished through evaporation of the coolant (helium, nitrogen). In the case of conduction cooling, however, a cryocooler is used to keep the system temperature stable. The complete approach of superconducting tape quenching is provided in Chapter 6. Because different time-varying currents or magnetic fields are involved in different systems, the AC losses must be calculated for each electrical power application. There are two approaches to get AC losses: transport current loss and magnetization loss. The current analysis has concentrated solely on current losses.

Types of AC loss

As previously stated, there are two forms of alternating current losses: magnetization losses and transport current losses. Both of these losses result in power dissipation, which raises the temperature of the superconductor. Because of the increased heat load, the cryogenic unit must keep the system temperature stable in order to prevent the superconductor from quenching. Magnetization Loss (Qm): This loss occurs when an alternating magnetic field is applied to a superconductor. These losses are divided into three types: hysteresis loss, coupling loss, and Eddy current loss. The applied magnetic field is the source of energy for such losses. Such losses are occurring as a result of the irreversibility produced by vortex pinning. Because of the pinning, the flux entering the superconductor is not the same as that leaving it. When a plot of magnetic induction, B, and magnetic field, H is drawn, a hysteresis loop is formed. In the absence of transport current, the energy loss per cycle is proportional to the area under the loop. Such hysteresis losses will result in heat dissipation, raising the temperature of the superconductor. Losses are proportional to the pinning, therefore the stronger the pinning, the greater the loss. This means that when the critical current of the type II superconductor increases, so do the hysteresis losses. Losses in Coupling Because of the presence of many superconducting filaments within a silver sheath, coupling losses are one of the issues for multi-filamentary conductors such as BSCCO (Bi-Sr-Ca-Cu-O). If the tapes are striated into filaments, such losses can be detected in second generation superconductors (YBCO). These losses occur when an eddy current generated by a changing magnetic field passes partially through the silver and partially through the superconductor between the filaments. It occurs when current passes from one filament to another, and the filaments are then connected together to form a single huge magnetic system that provides high resistance to current flow through the Silver matrix. Coupling losses are Ohmic losses that occur within the metal matrix.

Eddy Current Losses

When a time-varying external magnetic field penetrates a normal conductor, an induced time-varying electric field can cause current to flow. This current flow is known as eddy current in the tape, and it can cause significant ohmic energy dissipation if the magnetic field is perpendicular to the tape surface. Because eddy current losses are frequency dependent, they may be computed for a wide range of conductor shapes at low frequencies. Such losses can be reduced by raising the matrix's effective resistivity. Such losses were not taken into account in the current investigation.

Transport Current Losses

Hysteresis Loss: When alternating current flows through the superconducting tape, such losses occur. Because of the circulation of large currents, an induced self-field may form, which plays a significant role in such losses.

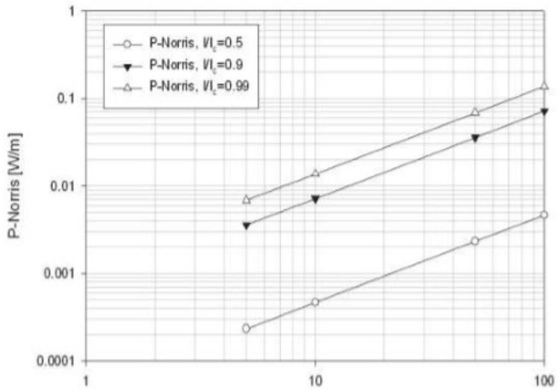
Flux Flow Loss: The depinning of the flux lines grows as the size of the transport current increases, and these lines begin to move in the superconductor. The heat dissipation caused by such a process is known as flux flow loss.

Analytical Techniques to evaluate AC losses

Several studies have been published that use analytical methodologies to calculate magnetization and transport current AC losses. AC losses computed using such analytical equations can be compared to losses computed using FEM techniques.

Norris Model

Norris proposed a method for calculating AC loss in a self-field. This analytical model is based on the idealised superconductor behaviour, which is equivalent to the London model. It is based on the assumption that if the current exceeds the critical values, the resistance of the superconductor rises abruptly, and that at constant current density, the ohmic voltage drop exactly balances the driving electromotive force (emf). This model assumes that the current density is unaffected by the ambient magnetic field, although it is widely known that it is affected not only by the size of the field, but also by its direction.



AC losses using Norris equation vs frequency of current

A plot has been constructed to determine the behaviour of the AC losses for various load factors and frequencies. Losses have been seen to rise with frequency and load factor.

The H-formulation

H-formulation is extensively utilized to solve the Maxwell equations for predicting the electromagnetic behaviour of the HTS in 2D because it provides correct results in less computational time. Comsol Multiphysics was utilized to complete the analysis, which included the use of PDEs to perform H-formulation analysis. H-formulations are commonly used to analyze AC losses because they are simple to apply boundary conditions relating to externally induced magnetic fields and current flow in superconductors, and the solution is found to converge at a faster pace than other methods.The computational domain is split with two subdomains: air and superconducting. The presence of magnetic substrate materials was not included in the investigation, and the Superpower tape (SCS 12050) was used for the study. By adding a few PDEs, the identical dependent variables are defined for both subdomains. The Maxwell's equations are applicable in both the superconducting and air sub-domains if 0 m = BH is assumed.

$$\nabla \times E = -\frac{dB}{dt} = -\mu_0 \frac{dH}{dt}$$

$$\nabla \times H = J$$

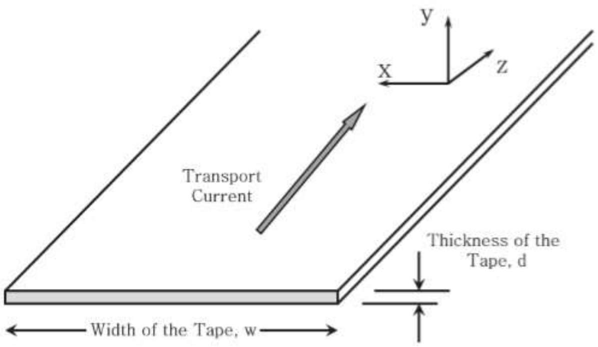
$$E = E_o \left(\frac{J}{J_c(B)} \right)^{n-1} \frac{J}{J_c}$$

The E-J power law is used to model the behaviour of superconducting material by assuming:

- The electric field E is always parallel to current density J
- In the E-J relation, E_0 signify the threshold electric field which is generally used to define the critical current density, Jc is equal to 10^{-4} V/m.

Modelling superconducting behaviour using power law is more appropriate than using the original Bean model (nfi) with a threshold voltage E= 1 V/m m. The power index 'n=30' is assumed to be a typical value for melt-processed YBCO tapes.

H-formulations in Cartesian Coordinates



Schematic of the High Temperature Superconducting tape used for FEM model

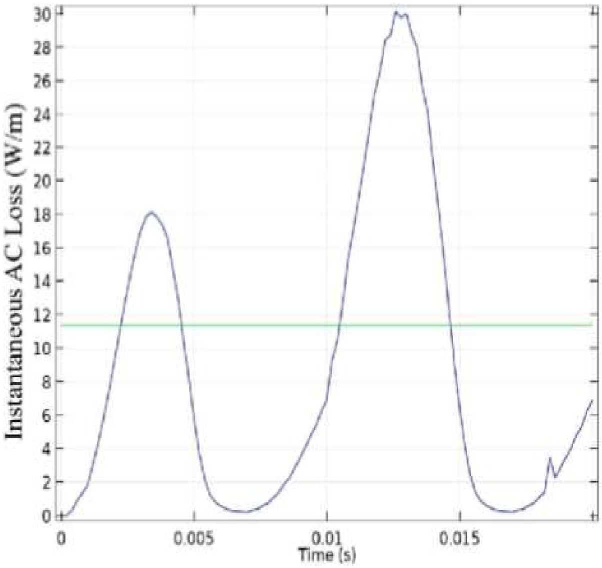
Assumptions

1. For the investigation, a 2D model was used.
2. The analysis was carried out on a single pancake coil.
3. To save computing time, a homogenised domain was employed instead of a multi-turned coil.
4. It is hypothesised that the turns are a bundle of parallel conductors made up of both conventional and superconducting materials.
5. External fields are not taken into account.

Validation of Computational Scheme

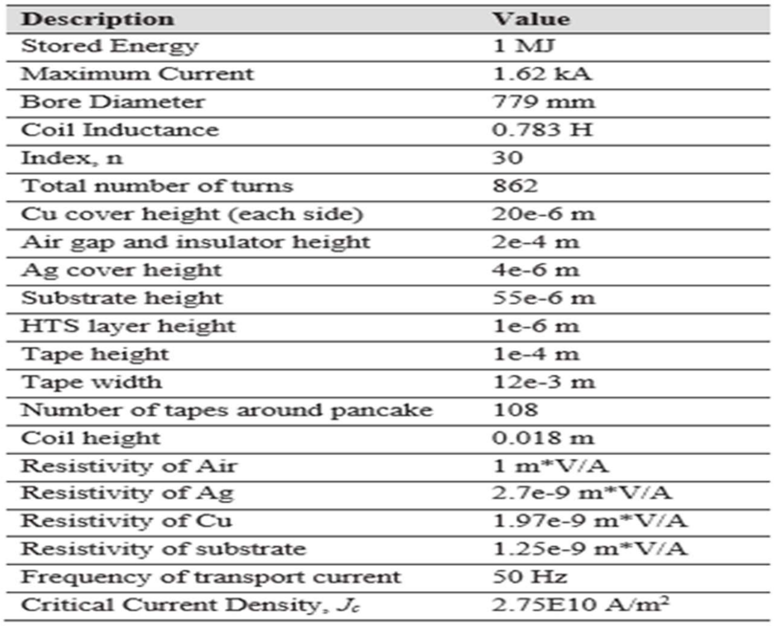
To validate the computational approach, the results of Zermeno et al. were replicated for instantaneous and average AC losses using the H-formulation at 77 K. The authors employed a homogenised approach to estimate the AC losses for coated conductors used in large-scale applications, and they studied 16 tapes, 32 tapes, and 64 tapes at a frequency of 50 Hz. The 4 mm's critical current

The operational currents chosen for the investigation were 50 A, 60 A, and 70 A, and the broad tape employed was 99.227 A. To account for local field effects, the Kim model was used, and the parameters involved in their investigation are listed in Table 2. A computational analysis was carried out for 32 stacked cassettes, through which 60 A current was conveyed at a frequency of 50 Hz. The analysis findings have been presented in Figure.



To corroborate the acquired simulated results with the work of Zermeno et al., the instantaneous losses (W/m) were determined using visual mapping using metric scale from the graph available in their research article, the values of which are tabulated.

Time (ms)	Instantaneous Loss (W/m)	Time (ms)	Instantaneous Loss (W/m)
0	0	-	-
1	3.1	11	17
2	9.2	12	26.2
3	17.1	13	30
4	16.8	14	21.2
5	6	15	7
6	0.8	16	0.5
7	0.3	17	0.1
8	1	18	1
9	3.6	19	3.3
10	7	20	7



Description	Value
Stored Energy	1 MJ
Maximum Current	1.62 kA
Bore Diameter	779 mm
Coil Inductance	0.783 H
Index, n	30
Total number of turns	862
Cu cover height (each side)	20e-6 m
Air gap and insulator height	2e-4 m
Ag cover height	4e-6 m
Substrate height	55e-6 m
HTS layer height	1e-6 m
Tape height	1e-4 m
Tape width	12e-3 m
Number of tapes around pancake	108
Coil height	0.018 m
Resistivity of Air	1 m*V/A
Resistivity of Ag	2.7e-9 m*V/A
Resistivity of Cu	1.97e-9 m*V/A
Resistivity of substrate	1.25e-9 m*V/A
Frequency of transport current	50 Hz
Critical Current Density, J_c	2.75E10 A/m^2

Conclusion

AC loss study was performed on the multi-turned pancake coil. The H-formulation computational approach was used to solve Maxwell equations. Edge elements have been found to reduce computational difficulties to a higher level and can be employed in AC loss estimates. To prevent complications, a 2D model for a homogeneous domain was solved. It has been determined that the number of turns has a major effect on the AC losses, and that such losses can be minimised by increasing the thickness of the substrate layer at the expense of magnetic density. COMSOL MultiPhysics software was used to conduct electro-thermal computational studies on superconducting tape. As buffer layers and interfacial resistance layers are treated as infinitely thin domains, the numerical model is estimated as two dimensional.

Acknowledgment

Sincere thanks to my supervisor and LIPS Research – INDIA, DL CARD – INDIA and president Jyothi NT madam for the industry support.

References

[1] John B, A., Jeyan, J. V. M. L., NT, J., Kumar, A., Assessment of the Properties of Modified Pearl Millet Starch. *Starch.* 2022, 2200160. https://doi.org/10.1002/star.202200160

[2] SumanRana,BhavinSoni,Dr. P. EbbyDarney,Jyothi NT, "EFFECTS OF T4 HORMONES ON HUMANBODY AND THEIR ANALYSIS", International Journal of Creative Research Thoughts (IJCRT), ISSN:2320-2882, Volume.10, Issue 10, pp.d332-d339, October 2022,

[3] Ashika Parveen1, JV MurugaLal Jeyan[2], Jyothi NT[3] International Study on Application of Value Stream Mapping to Identify the Necessity of Lean System Implementation , International Journal of Scientific Research in Engineering and Management (IJSREM) Volume: 06 Issue: 09 | September - 2022 Impact Factor: 7.185 ISSN: 2582-3930

[4] JV MurugalalJeyan, Jyothi NT RashiKaushik Systematic Review and Survey on Dominant Influence of Vedas and Ignorance Transpired in Space Science and Aviation", International Journal of Emerging Technologies and Innovative Research (www.jetir.org), ISSN:2349-5162, Vol.9, Issue 7, page no.b490-b493, July-2022,

[5] JV MurugalalJeyan, Jyothi NT , Boopesh Raja, Rajarajan G "THEORY STRATEGY OF SUBSONIC WIND TUNNEL FOR LOW VELOCITY ", International Journal of Emerging Technologies and Innovative Research (www.jetir.org), ISSN:2349-5162, Vol.9, Issue 6, page no.j572-j580, June-2022, Available :http://www.jetir.org/papers/JETIR2206973.pdf

[6] JV MurugalalJeyan, Jyothi NT, Reshmitha Shree, Bhawadharanee S, Rajarajan, THEORETICAL STUDY OF HYPERSONIC WIND TUNNEL TEST FACILITY IN INDIA ", International Journal of Emerging Technologies and Innovative Research (www.jetir.org), ISSN:2349-5162, Vol.9, Issue 6, page no.j512-j518, June-2022, Available

[7] JV MurugalalJeyan, Jyothi NT , V S DevikaThampuratty, B Nithin, Rajarajan, CONCEPT DESIGN AND DEVELOPMENT OF SUPERSONIC WIND TUNNEL ", International Journal of Emerging Technologies and Innovative Research (www.jetir.org | UGC and issn Approved), ISSN:2349-5162, Vol.9, Issue 6, page no. ppj209-j217, June-2022, Available at :

[8] MuthuVenkatesh, Rajarajan G Jyothi NT JV MurugaLalJeyan "Systematic Survey of Wind Tunnel Test facility in India", International Journal of Emerging Technologies and Innovative Research (www.jetir.org), ISSN:2349-5162, Vol.9, Issue 6, page no.h830-h840, June-2022, Available :http://www.jetir.org/papers/JETIR2206795.pdf

[9] AshikaParveen, JV MurugaLalJeyan, Jyothi NT "Investigation Of Lean Developments And The Study Of Lean Techniques Through Event Studies" Internation Journal for Science and Advance Research In Technology, 8(4)

[10] P Gopala Krishnan, JV MurugaLalJeyan, Jyothi NT "Novel Evaluation Of Aircraft Data Structure Optimization Techniques And Opportunities" International Journal for Science and Advance Research In Technology, 8(4)

[11] SuryanshUpadhyay, JV MurugalalJeyan, Jyothi NT Preliminary Study on Brain Computer Interface © August 2021| IJIRT | Volume 8 Issue 3 | ISSN: 2349-6002 IJIRT 152537 INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN TECHNOLOGY 720

[12] Sruthi.s.kumar, JyothiNt ,JvMurugalaljeyan . Computational Turbine Blade Analysis with Thermal Barrier Coating International Journal of Engineering Research and Applications www.ijera.com ISSN: 2248-9622, Vol. 12, Issue 4, (Series-I) April 2022, pp. 01-08, DOI: 10.9790/9622-1204010108

[13] Systematic Survey, Performance Evaluation, and Truth Flow Analysis of Two Subsonic Wind Tunnels with Two-Hole Spherical Flow Analyzer - AkhilaRupesh and J. V. MurugaLalJeyanIn Production Pub Date: October 2022 Hardback Price: $159.95 USD | £124.00 Hard ISBN: 9781774911303 https://www.appleacademicpress.com/optimization-methods-for-engineering-problems-/9781774911303

[14] K.S. Priyanka, J.V.M.L. Jeyan and S. Vihar. 2022. Investigation of Flow Separation Over NACA 24015 and 24021 Airfoils using Flow Injection Method, Int. J. Vehicle Structures & Systems, 14(3), 300-305. doi: 10.4273/ijvss.14.3.02.

[15] P. S. RAMESH, J. V. MURUGA LAL JEYAN, *Comparative Analysis of Fixed-Wing, Rotary-Wing and Hybrid Mini Unmanned Aircraft Systems (UAS) from the Applications Perspective*, pp. 137-151, https://doi.org/10.13111/2066-8201.2022.14.1.12-INCAS BULLETIN, Volume 14, Issue 1/ 2022, pp. 137 – 151 Published: March 2022

[16] P. S., R., & J. V. MurugaLal, J. (2022). Hover performance analysis of coaxial Mini unmanned aerial vehicle for applications in mountain terrain. Aviation, 26(2), 112–123. https://doi.org/10.3846/aviation.2022.16901
Published in Issue Jun 21, 2022

[17] P.S., R. and J.V., M.L.J. (2022), "Evaluation of design criteria for mini unmanned aircraft systems (UAS) applications", Aircraft Engineering and Aerospace Technology, Vol. 94 No. 3, pp. 327-335. https://doi.org/10.1108/AEAT-03-2021-0089 Issue publication date: 10 February 2022

[18] AishwaryaDhara and JeyanMurugaLal 2021 IOP Conf. Ser.: Earth Environ. Sci. 889 012068
https://iopscience.iop.org/article/10.1088/1755-1315/889/1/012068/meta

[19] R. Sabari VIHAR, J. V. MurugaLal JEYAN, K. Sai PRIYANKA, *Effect of camber on the flutter characteristics of different selected airfoils*, pp. 215-223, Published: September 2021 https://doi.org/10.13111/2066-8201.2021.13.3.18

[20] R. Balaji and M. L. Jeyan, "Performance analysis on varies bluff bodies at hypersonic speed," 2020 International Conference on Interdisciplinary Cyber Physical Systems (ICPS), 2020, pp. 62-67, doi: 10.1109/ICPS51508.2020.00017. https://ieeexplore.ieee.org/document/9434600

[21] A. Rupesh, J. V. MurugaLalJeyan, , "Aerodynamic Design and Flow Analysis of Two Taping Spherical Flow Analyser and Mirror Edge Flow Analyser for Subsonic Wind Tunnel Calibration," 2021 International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT), Bhilai,India,2021,pp.1-6,doi:10.1109/ICAECT49130.2021.9392535, https://ieeexplore.ieee.org/document/9392535

[22] Ramesh, P.S. and MurugaLalJeyan, J.V. (2021), "Terrain imperatives for Mini unmanned aircraft systems applications", International Journal of Intelligent Unmanned Systems, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/IJIUS-09-2020-0044

[23] Akhilarupesh, JV MurugalaljeyanExperimental and Computational Evaluation of Five Hole Five Probe Flow Analyzer for Subsonic Wind Calibration - International Journal of Aviation, Aeronautics, and Aerospace , Published by Scholarly CommonsEmbry-Riddle Aeronautical University Volume 7 Issue 4 Article 3 2020

[24] Ramesh PS, JV MurugalaljeyanMini Unmanned Aerial Systems (UAV) - A Review of theParameters for Classification of a Mini UAV - International Journal of Aviation,Aeronautics, and Aerospace , Published by Scholarly CommonsEmbry-Riddle Aeronautical University Volume 7 Issue 3 Article 5 2020

[25] K.SaiPriyanka , J V MurugaLalJeyan*, R.SabariVihar. (2020). A Review on a Reassess Swot up on Airfoil Stall and Flow Separation Delay for a Range of Limitations Associated with Aerodynamics and Wing Profile. International Journal of Advanced Science and Technology, 29(06), 7659-7668.

[26] R. SabariVihar, J. V. MurugaLalJeyan, K. SaiPriyanka. (2020). A Review on Aerodynamic Parameters, Methodologies and Suppression Techniques Explored in Aircraft Wing Flutter. International Journal of Advanced Science and Technology, 29(04), 3494

[27] AkhilaRupesh, Dr. J V MurugaLalJeyan. (2020). Performance Evaluation of a Two Hole and Five Hole Flow Analyzer for Subsonic Flow. International Journal of Advanced Science and Technology, 29(05), 7512-7525

[28] JV MurugalaljeyanKavya S nair Amit Kumar Thakur Deepak Kumar Aerodynamic stability on piezoelectric multi Rotor UAV with numerical case learning European Journal of Molecular & Clinical Medicine, 2020, Volume 7, Issue 7, Pages 1558-1568 https://ejmcm.com/article_4636.html

[29] J V MurugalalJeyan , Dr. M. Senthil Kumar, "Performance Evaluation of Yaw Meter With the Aid of Computational Fluid Dynamic" , International Review of Mechanical Engineering (IREME). ISSN: 1970-8734, Vol No. 8,Issue 02 .

[30] J V MurugalalJeyan ,Dr. M. Senthil Kumar , "Performance Evaluation for Multi-Hole Probe With the Aid of Artificial Neural Network" International Journal of Theoretical and Applied Information Technology (JTAIT). ISSN 1992-8645Vol No: 65 , Issue 3 , PP: 665 July 31, 2014