01 Jan 1981

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A. Sances

S. J. Larson

J. F. Szablya

J. Derald Morgan
Missouri University of Science and Technology

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/ele_comeng_facwork/4926

Recommended Citation

A. Sances et al., "High Voltage Powerline Injury Studies," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS thru 100, no. 2, pp. 552 - 558, Institute of Electrical and Electronics Engineers, Jan 1981.
The definitive version is available at https://doi.org/10.1109/TPAS.1981.316911

IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 2, February 1981

HIGH VOLTAGE POWERLINE INJURY STUDIES

A. Sances, Jr., Senior Member, IEEE
Medical College of Wis. & Wood VAMC
8700 West Wisconsin Avenue
Milwaukee, Wisconsin 53226

J. F. Szablya, Fellow, IEEE
Washington State University
Pullman, Washington 99164

J. D. Morgan, Senior Member, IEEE
University of Missouri - Rolla
108 Electrical Engineering
Rolla, Missouri 65401

J. B. Myklebust, Member, IEEE
Neuroscience Research Lab
Veterans Adm. Medical Center
Wood, Wisconsin 53193

S. J. Larson
Medical College of Wis. & Wood VAMC
8700 West Wisconsin Avenue
Milwaukee, Wisconsin 53226

Abstract - Current pathways and reconstructions of human injury after contact with distribution powerlines are not well understood. The impedance, currents, and modes of tissue destruction are rarely known. Eight anesthetized hogs, weighing 68 to 90 kg, were used in studies with potentials ranging from 2,100 to 14,400 volts. Electrical contact was made between the hindlimbs, from the hindlimb to forelimb, and over other regions of the body. Currents from 4 to 70 amperes rms and impedances ranging from 130 to 477 ohms were measured. Phase angles up to 40° were observed.

INTRODUCTION

The number of injuries produced by commercial current are a serious world problem. Contact with transmission and distribution potentials usually produce devastating explosive burns [1-11]. The injuries are associated with enormous joulean heat. Deep tissue damage occurs at solid contact points. Arc temperatures of approximately 4,000°C occur when the conductor is brought into proximity of the biological subject. Associated flame injuries from clothing fires often complicate reconstruction of the accident [12]. Tissue injury occurs when a temperature of 80°C is maintained for 0.5 seconds; in contrast, contact at a temperature of 60°C will produce injury if sustained for 5 seconds [13,14].

Extensive literature exists describing the current flow and impedance at voltages in the household range [12,15]. A recent review of electrical injuries including perception or threshold for sensation levels, let-go currents, respiratory effects, ventricular fibrillation currents, lightning injuries, electrical burns and surgical management, as well as current density and impedance, has been given elsewhere and will not be repeated here [16].

A review of the literature also makes obvious the lack of information describing the tissue impedance, currents, and modes of tissue destruction at powerline potentials above 1,000 V. The studies described in this paper were therefore conducted to determine the electrical parameters and temporal events associated with typical high voltage contact in living animals.

F 80 271-7 A paper recommended and approved by the IEEE Transmission & Distribution Committee of the IEEE Power Engineering Society for presentation at the IEEE PES Winter Meeting, New York, NY February 3-8, 1980. Manuscript submitted September 10, 1979; made available for printing December 10, 1979.

METHODS

Eight hogs (Sus scrofa) weighing 68 to 90 kg were used for these studies. Each of the hogs was sedated with an initial dose of 15 mg/kg Ketamine Hydrochloride mixed with 0.75 mg/kg of Acepromazine. An initial dose of Nembutal 10 mg/kg was used for anesthesia and continued maintenance levels were administered as required. The animals were placed on a 3 x 6 m rubber insulating pad. For some experiments, a 40 x 60 cm steel plate, placed under the lateral aspect of the hindlimb of the animal, was one electrode. The animal was shaved and Cambridge electrode paste was applied liberally to the hindlimb and to the plate to establish positive contact between the animal and the electrode. For other studies, the plate was dry and the animal was unshaved to simulate working contact impedances.

For the wire-to-wire contacts, a #4 stranded copper wire solidly attached to one of the hindlimbs was used in place of the steel plate. Electrode paste was not used in the wire to wire studies. Ten to twelve cm of wire was either wrapped around the region of the ankle of the rear leg or fixed along the axis on the lateral aspect of the distal portion of the limb.

In all cases, a #2 ACSR wire was used to make contact with various portions of the animal, including the hindlimb, the forelimb, the head, and ear. In one study (Animal #1, P-H b), a 15 to 20 cm length of #2 ACSR wire was brought in contact with the animal. In all other studies, 2 to 5 cm of the wire tip was used for parallel contact with the tissue. For each region, approximately 5 wire contacts were made. Each animal study was completed within 15 minutes and no more than 5 minutes after the animal expired.

The electrical studies were conducted three poles out of the South Ephrata substation, Public Utility District No. 2 of Grant County in the State of Washington. The test circuit is shown in Fig. 1.

The pole mounted transformer (T1), manufactured by RTE, had a rating of 167 kVA at 14,000-120/240 V and an impedance of 2.6%. Transformer T2 was Allis Chalmers Type CBS rated 100 kVA at 14,400-120/240 V and Z=2.4% and T3 was a Westinghouse Style 1607319 rated 25 kVA at 2,400-120/240 V and Z = 2.6%. The current transformer was Westinghouse Style 1356062, 25/50-5A, 15 kV.

A Honeywell Visicorder Model 1858 was used. The current of the current transformer (CT) and 120/240 V voltage was displayed. To have a direct voltage reading, a Simpson Model 260 Series 6 multimeter with a high voltage probe was connected to the test voltage and its readings recorded. The test current was measured with an ammeter in the secondary of the CT, and by a Simpson Model 150 clamp and Model 260 meter on one wire to the animal.

A Yellow Springs Instruments Model 41TC/Temperature System with Model 530 probes was used to measure the tissue temperature. The time constant of the probes was 0.1 second nominal. The thermistor was placed in the subcutaneous tissue of forelimb or hindlimb, 12 to 20 cm proximal to the region of contact with the #2 ACSR wire conductor. In one study (Animal #4), 0.9% normal saline (which approximates human perspiration) was liberally applied to the electrode sites. In the other study (Animal #5), the saline was applied to the body of the animal between the forelimb and hindlimb electrodes.

During the tests, no precipitation occurred, the air temperature ranged between 25° and 33°C; the relative humidity was 20 to 30% and the ground wind was steady at approximately 14 to 16 km/h.

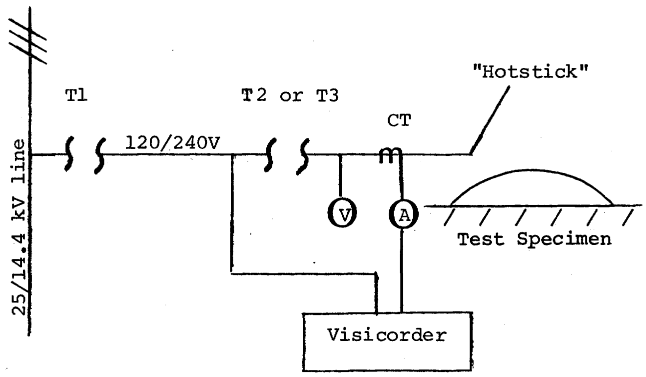

Fig. 1 Circuit diagram

RESULTS

All voltages and currents reported are rms values. Table 1 shows the type and number of tests conducted. Two pigs were studied at 2,100 volts; three at 7,200; and three at 14,400. At 7,200 V input, the potentials dropped to between 6,200 and 6,600 V (Animals #3-5). For Animal #6, only one side of the secondary of the feed transformer was connected which resulted in greater voltage drops than in Studies #7 and 8 when both secondaries were connected. Less than 5.0% voltage drop was observed at 2,100 input volt levels. Two series of studies were done in the same body region (denoted by "a","b") for Animals #1, 4, and 5. Studies #4a and 5a were conducted on the limbs opposite to those of #4b and 5b. Table 1 shows the currents for the first contacts to the tissues. The currents and voltages shown represent the average of the envelope over 5 to 10 cycles. The averaged values of current for each series of 5 contacts in the same region and the standard deviation is indicated by a bar over the values. Impedance values are the average for each series of 5 contacts. The phase angle as available was capacitive in all cases.

2,100 Volt Studies

In the plate to hindlimb studies (P-H) done with a shaved animal and electrode paste, Animal #1 shows a decrease in resistance by approximately 50% when 15 to 20 cm of the #2 ACSR wire was brought into parallel tissue contact, (Table I, Animal No. 1, P-H#), compared to when 2.0 to 5 cm of the wire was touched to the animal. The currents and calculated impedances shown for the second animal without the conductive paste were similar to those obtained from Series "a", P-H and P-F, Animal #1. Greater currents were measured in the hindlimb to hindlimb study than in the wire to wire hindlimb to forelimb (H-F) studies of Animal #2. The distances between electrodes were approximately 1.2 m for hindlimb to the forelimb and 0.3 m for hindlimb to hindlimb. Both animals expired, probably secondary to cardiorespiratory induced side-effects with repeated hindlimb to forelimb current applications. No differences in current were observed within the study period after the animals expired.

The initial values of current are greater than those recorded with continued contact. The wire to wire currents are lower than those from the plate to the wire. A capacitive angle of 21 degrees was observed in the hindlimb to forelimb study of Animal #2. Tissue was destroyed in the continued contact series. The currents reached their maximum values upon initial contact (4 ms) with the tissue and remained at these levels unless the contacting electrode was moved away from the preparation, or gross damage to the tissue reduced the area of the current carrying pathway. The skin appeared to breakdown immediately. Full thickness, third degree burns were followed by boiling and splattering of the subcutaneous fluids. The duration of contact for these studies ranged from 0.1 to several seconds. Some burns were observed at the site of the large metal plate in Animal #2. Punctate arcing over a sphere of approximately 2 cm diameter occurred. The currents commenced when the #2 ACSR electrode was moved within approximately 0.5 cm of the animal. The currents appeared to commence from sharp surfaces of the electrode to the hair of the animal. The tissue reached 100°C within approximately 0.3 seconds (Fig. 2).

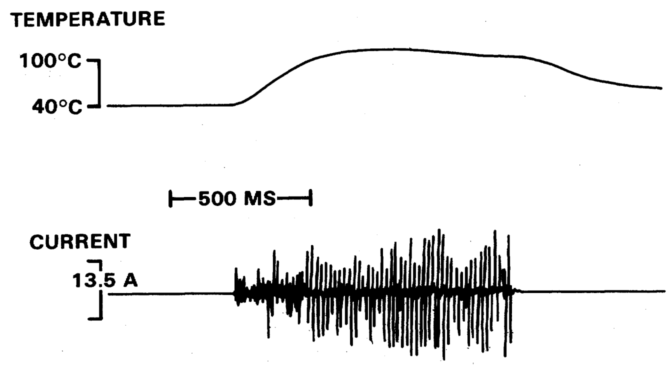

Fig. 2 Current and temperature for Animal #2 with plate on hindquarter touching hindlimb with #2 ACSR wire. The temperature probe in subcutaneous tissue was 15 cm proximal to the contact point. Arcing at first 250 ms.

7,200 Volt Studies

Comparison of Animals #3 and 4 shows a higher current value for the plate to hindlimb and plate to forelimb studies than for the wire to wire series. For Animal #3 the wire to wire studies from the hindlimb to the forelimb show a decreased current with an approximate 40% increase in impedance compared to the corresponding plate experiments. The hindlimb to forelimb and plate to hindlimb phase angle for Animal #3 was 40° capacitive and 20° capacitive for the hindlimb to ear. Figure 3 shows the record of voltage and current for the hindlimb to forelimb study of Animal #3. Most of the ear was destroyed after two 0.1 to 0.2 second contacts. The currents then flowed freely over the cranial surface of the animal. When saline was applied at the electrode sites of Animal #4 in the hindlimb to forelimb studies, the average current was increased from 19.8 to 24.9 A. For Animal #5, saline application across the body did not produce significant differences in current or impedance values, however an arc envelopment up to 0.75 m between the hindlimb and forelimb electrodes was observed, compared to approximately 0.25 m without saline.

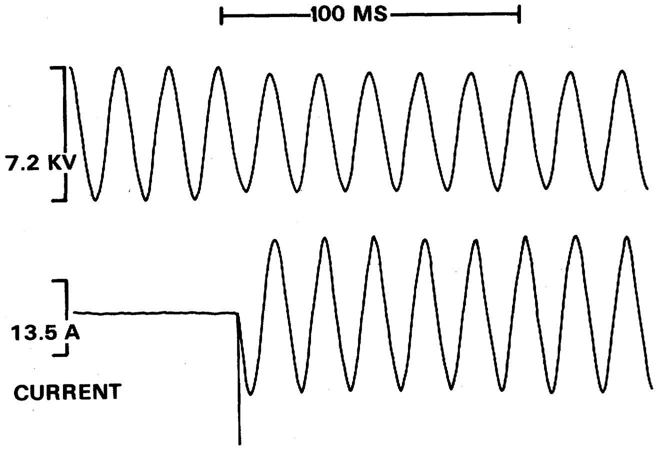

Fig. 3 Voltage (upper) and current (lower) for hindlimb to forelimb study of Animal #3. A capacitive phase shift of approximately 40° is present following contact.

Following two to three contacts, the fixed wire on the hindlimb routinely showed large arcing and observable flame over a sphere of approximately 20 cm diameter. Arcing increased with the number of contacts. The tissue was destroyed under the region of the wire within several seconds and the bones were visible. A decrease in impedance was recorded when substantial arcing took place. The currents and arcing appeared to occur over regions of viable tissue taking the path of lowest impedance. In the hindlimb to forelimb Study #5a, the contact wire was perpendicular to the wrist for a period of approximately 16 seconds until total transsection occurred. The applied energy for transsection was approximately 2,000 kWs (neglecting phase angle). Skin, fat and muscle tissue were destroyed under the #2 ACSR conductor within approximately 5.0 seconds; the remaining 11 seconds was required for bone transsection. For this study, the current decreased from an initial value of 25 to 14.8 A (Fig. 4).

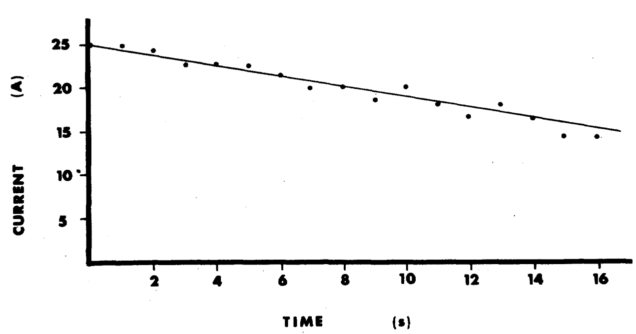

Fig. 4 Plot of current versus time of application for Animal #5 hindlimb to forelimb study. Transsection occurs at 16 seconds.

The time required for tissue destruction appeared to be inversely proportional to the VA measured in each of the studies. Muscular contraction was noted for each instance of current contact. Currents appeared to enter at the contact site and traveled through the tissues. The animal routinely expired following contact between the forelimb and the hindlimb.

Gross dissection and observation within 30 minutes of the tests showed tissue destruction up to 25 cm proximal to the point of electrode contact. The tissue temperature remained elevated for up to 30 minutes following current cessation. It was not possible to compare vascular, neural or muscle damage. However, it appeared that the bones were often preserved while the overlying tissues were destroyed. Boiling and splattering of the biological fluids clearly indicated temperatures above 100°C.

<u>14,400 Volt Studies</u>

Because of transformer connection, large voltage drops were observed in Animal Study #6. Electrode paste was used. With contact, the potentials dropped to 9,000 to 10,000 V. An average current of approximately 46.4 A, and impedance of 203 Ω was observed for the plate to hindlimb study. Somewhat lower values were observed for the plate to forelimb study.

The transformer connection was changed for Animal #7. The wire to wire studies ranged from an average of 60 A for the hindlimb to forelimb studies to an average of 57.2 A for the hindlimb to head studies. These larger values were observed with significant arc envelopment of the surface of the animal. In the wire to wire studies of Animal #7, peak currents of up to 70 A were observed. At the hindlimb and forelimb, arcs up to 45 cm in diameter were observed. Currents measured in Animal #8 were similar to those of Animal #7.

Tissue was often blown away with contact. For these studies, the currents appeared to be limited and were not substantially greater than those observed in the 7,200 voltage series. However, substantially more arc development was present with contact areas. The currents and impedance values were somewhat more variable because it was necessary to routinely break the electrical contact by moving the #2 ACSR electrode away from the animal. When this was done, large arcs often traveled almost across the entire body. It was not possible to accurately determine the levels of sounds associated with the arcing contacts. The contacts and resulting arcing were audible for at least several hundred meters. Furthermore, it was difficult to determine the spacing over which initiation of arcing commenced while advancing the #2 ACSR wire towards the tissue.

For the hindlimb to forelimb study of Animal #7, approximately three seconds were required for full transsection at the wrist. This occurred with average currents of approximately 60 A. Ignoring the phase angle, the energy required was (60 A) x (12,500 V) x 3 s = 2,250 kWs. The phase angles of the impedance were similar to those observed with 7,200 volt application; however, the majority of the impedances were somewhat lower.

<u>Wire Damages</u>

Pitting on the wires, whether #2 ACSR or #4 stranded copper was minimal. Pitting was heavier at 14.4 kV than at 7.2 kV as expected. Tissues burned onto the wires and colored them dark. Figure 5 shows a sample of the #2 ACSR wires used in conjunction with Animal #4 at 7.2 kV.

Other metallic objects attached to the animals behaved similarly.

Fig. 5 #2 ACSR wire used in 7.2 kV study of Animal #4.

DISCUSSION

Previous estimates of 500 Ω are commonly quoted as the minimum resistance of the human body between major extremities for estimating shock currents during industrial accidents [15]. For defibrillation studies, well-jellied large electrodes of approximately 8.9 cm diameter were applied to the praecordium. Impedances as low as 30 Ω are observed when ms pulses or short duration high frequency current are used [17]. Transthoracic impedance values of approximately 58.2 Ω have been reported for defibrillation systems over a population of 175 subjects; values ranging from 17 to 44 Ω for electrodes applied across the ventricles were also reported [18]. These values are probably low because the studies are carried out in animals using large, well-jellied electrodes applied to the tissue with substantial pressure exerted. Lower values of impedance are expected when electrodes are applied to internal organs. Furthermore, the short duration capacitor discharge or high frequency currents would reduce these values.

The tissue destruction observed in our studies appeared to be proportional to the energy imparted [16]. Transsections of the limbs at 7,200 and 14,400 volts required an applied energy of approximately 2,000 kWs. Because capacitive angles of 40° were observed, this value might be approximately 25% lower. The large arc envelopment of the test subject at 14,400 V was probably increased by the ground breeze of 14 to 16 km/h flowing from the upper to lower region of the animal. While the impedance had capacitive phase angles up to 40°, in most instances they could be essentially considered resistive. The area of contact appeared to be a determining factor for the current and impedance at each respective voltage level. While some decrease in impedance occurred with time (Fig. 3), the current was not substantially limited by tissue destruction and appeared to follow an alternative pathway through adjacent tissues. The skin was punched through within 4 ms. With good contact, the energies available maintained the current relatively constant. Since bubbling and spattering of the tissue occurred at application of the higher voltages, it is clear that the tissue temperatures were in excess of 100°C. While the subcutaneous layers of fat in the pig are often thicker than those of man, these studies probably approximate currents which flow through the human during industrial powerline accidents. Furthermore, the subjects are often grounded at one area or are holding onto a wire while another conductor approaches the victim. No differences in current were observed up to five minutes following animal death. Others have reported little change for substantially longer periods [15]. No conclusions should be advanced regarding fibrillation of the animals secondary to application of currents using these studies; however the animals routinely developed cardiopulmonary difficulties secondary to forelimb to hindlimb contact.

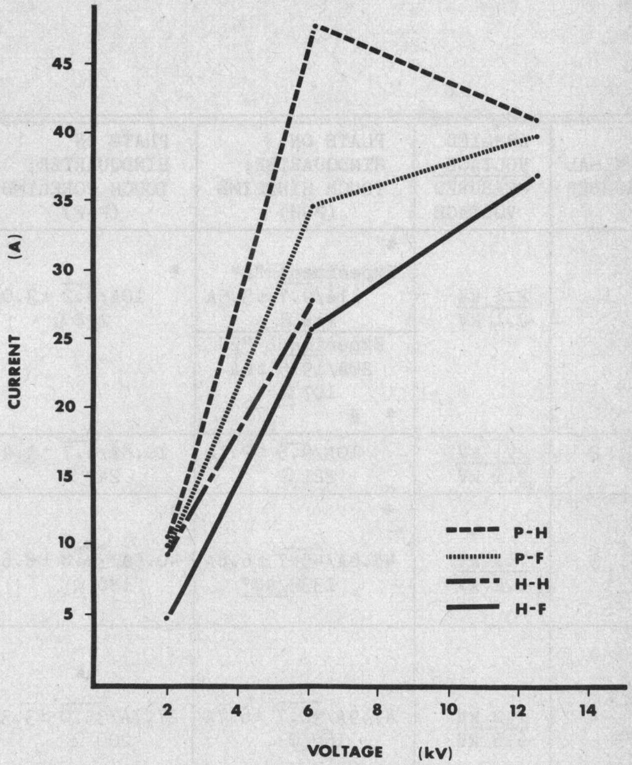

Fig. 6 Current ordinate versus voltage, abscissa for Plate to Hindlimb (P-H), Plate to Forelimb (P-F), Hindlimb to Hindlimb (H-H), and Hindlimb to Forelimb (H-F). Plots of first contact on animal.

The hog was used in these studies because it has skin which bears a close anatomical relationship to that of man [19]. It is used to replace human skin (xenograft). The higher impedance values for the wire to wire contacts are probably secondary to contact area effects when contrasted to the plate to limb studies. The well-jellied plate studies suggest that this preparation should approach the highest values of current which might be experienced.

The 7,200 and 14,400 V experiments show that significant damage is produced with contact times of less than one second.

Minimal pitting was observed at the #2 ACSR and copper wires for all studies. The current values for the first contact were generally greatest (Fig. 6, Table I). The increase in impedance with higher voltages was probably due to arcing, tissue fluid boil off, rapid tissue destruction and difficulty in contact maintenance.

It was not possible to conduct temperature studies at 7,200 and 14,400 V; however, at 2,100 V, maximum temperature rise in the tissue 12 to 20 cm away from current application occurred within 0.3 second. At 7,200 and 14,400 V, the temperatures remained elevated for 10 to 30 minutes following current cessation. While the histological studies have not been completed for these experiments, the gross observations suggest tissue damage occurs at regions remote to the site of current application [3,5,6]. These studies show that impedances substantially below 500 ohms can occur in the living subject. Previous impedance estimates derived from low voltage studies [15] are probably too large for high voltage powerline investigation.

ANIMAL NUMBER	APPLIED VOLTAGE / MEASURED VOLTAGE	PLATE ON HINDQUARTER; TOUCH HINDLIMB (P-H)	PLATE ON HINDQUARTER; TOUCH FORELIMB (P-F)	WIRE ON HINDLIMB; TOUCH HINDLIMB (H-H)	WIRE ON HINDLIMB; TOUCH FORELIMB (H-F)	WIRE ON HINDLIMB; TOUCH HEAD (H-Head)
1	2.1 kV / 2.1 kV	* Experiment "a" 11A/9.7 ±3.5A 216 Ω Experiment "b" 20A/19.5 ±6A 107 Ω * #	* 10A/9.2 ±3.0A 228 Ω			
2	2.1 kV / 2.1 kV	10A/9.5 ±2.1A 221 Ω	10.8A/8.7 ±1.4A 240 Ω	9.4A/5.5 ±2.1A 380 Ω	4.7A/4.4±0.8A 477Ω/21°	
3	7.2 kV / 6.2 kV	* 48.6A/45.7 ±6.8A 133Ω/40°	* 40.5A/34.8 ±8.6A 180 Ω	28.4A/32 ±5.0A 190 Ω	33.8A/28.4 ±7.1A 250Ω/40°	28.4A/29.1 ±1.4A 227Ω/20° TOUCH EAR
4	7.2 kV / 6.6 kV	47.9A/38.7 ±6.7A 168 Ω	27.7A/33.0 ±3.3A 200 Ω		Experiment "a" 18.2A/19.8 ±2.1A 348Ω/16° Experiment "b" 24.3A/24.9 ±1.4A 270Ω/16° S_e	
5	7.2 kV / 6.6 kV				Experiment "a" 24.9A/19.3±3A 342 Ω Experiment "b" 22.0A/20.1 ±4A 328 Ω S_b	
6	14.4 kV / 9-10 kV	* 41.5A/46.4 ±10.4A 203 Ω	* 39.8A/41.8 ±5.6A 240 Ω			
7	14.4 kV / 12.5 kV				37.8A/60 ±14A 207Ω/33°	50.6A/57.2 ±4.6A 215Ω/33°
8	14.4 kV / 12.5 kV		* 54A/52.6 ±2.0A 235Ω/26°		37.8A/41.8 ±6.4A 320Ω/26°	

TABLE I Voltage: Nominal test voltage applied/measured voltage during tests

Test Results: First touch amperage/Average amperage ± Standard deviation
Average impedance in ohms/phase angle in degrees, current leading

* Hindquarter shaved; electrode paste applied to hindquarter and to steel plate
\# 15 to 20 cm of the #2 ACSR wire was brought into contact with the animal
S_e Saline applied in the vicinity of the electrodes
S_b Saline applied to the body of the animal

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Acknowledgement

The authors wish to thank the Public Utility District No. 2 of Grant County for providing facilities, equipment and manpower for the tests. Special thanks are due to Mr. Doug Hein for his enthusiastic support and to Mr. Bud Bellinger for his help.

Anthony Sances, Jr., was born in Chicago, Illinois, on July 13, 1932. He received the B.S.E.E. degree in 1953, the M.S. degree in physics from De Paul University, Chicago, Illnois, in 1959, and the Ph.D. degree in biomedical engineering from Northwestern University, Evanston, Illinois, in 1964.

From 1953 to 1959, he was Project Engineer in the Research Department of American Machine and Foundry. He was Manager of the Advanced Research Department of Sunbeam Corporation, Chicago, Illinois, and was Vice-President and Director of Research at San-Bar Corporation, also in Chicago. Since 1964, he has been with the Department of Electrical Engineering at Marquette University and the Department of Neurosurgery at the Medical College of Wisconsin, Milwaukee, Wisconsin, where he is Professor and Chairman of Biomedical Engineering.

Dr. Sances is a member of the IEEE Engineering in Medicine and Biology Group, the Instrument Society of America, and twenty additional professional societies. He is a Registered Professional Engineer in the State of Wisconsin, a member of the Milwaukee Chapter of the Wisconsin Society for Professional Engineers, a certified Clinical Engineer, a consultant to the National Science Foundation, and a Study Section Member for the National Institutes of Health. He is the author of more than 200 papers and 4 books.

John F. Szablya was born in Budapest, Hungary on June 25, 1924. He attended the Jozsef Nador University of Budapest, where he received diplomas in mechanical engineering (majoring in electrical engineering), economics, and education (majoring in philosophy and psychology), and his doctorate in economics, in 1947 and 1948.

Between 1947 and 1956, he worked as a design engineer for the Ganz Works. Between 1957 and 1963, he was a member of the faculty of the Department of Electrical Engineering at the University of British Columbia (Canada). In 1963, he joined the faculty of Washington State University in Pullman, Washington, where he is now Professor of Electrical Engineering and Environmental Sciences. At present, he also holds the position of External Examiner and OAS Visiting Professor to the University of the West Indies.

Dr. Szablya has been the author or co-author of more than 30 papers appearing in various journals,

including the IEEE Transactions on Power Apparatus and Systems and the Proceedings of the American Power Conference.

He is a Registered Professional Engineer in the State of Washington and the Province of British Columbia and he is a member of the Tensor Society of Great Britain and an honorary member of Sigma Xi.

John Derald Morgan was born in Hayes, Kansas, on March 15, 1939. He received the B.S. degree in electrical engineering from Louisiana Tech University, the M.S. degree in electrical engineering from the University of Missouri-Rolla, and the Ph.D. degree in electrical engineering from Arizona State University, in 1962, 1965, and 1968 respectively.

From 1963 to 1973, he was Associate Professor of Electrical Engineering at the University of Missouri - Rolla, and since 1976, he has been the Emerson Electric Professor of Electrical Engineering, Associate Director of the Center for International Programs and Studies, and the Power Area Chief.

Dr. Morgan is a member of the IEEE Power Society Power Systems Engineering Committee the IEEE International Practices Subcommittee and Education Committee, and the American Society of Electrical Engineers. He is a Registered Professional Engineer in the State of Missouri.

His major areas of interest are in power system analysis, planning and control, and in high voltage engineering.

Joel B. Myklebust is a biomedical engineer in the Neuroscience Laboratory of the Veterans Administration Medical Center at Wood, Wisconsin. He received his B.S. degree from the University of Iowa in 1971 and his M.S. degree from the University of Rochester in 1972, both in electrical engineering. Currently, he is a Ph.D. candidate in Biomedical Engineering at Marquette University in Milwaukee, Wisconsin. His research interests include the therapeutic applications of electrical current to the nervous system and the recording of neuroelectric potentials for diagnostic purposes. He is a Registered Professional Engineer in the State of Wisconsin.

Sanford J. Larson was born in Chicago, Illinois, on April 9, 1929. He received the B.A. degree from Wheaton College, Wheaton, Illinois, in 1950 and both the M.D. and Ph.D. degrees from Northwestern University, Evanston, Illinois in 1954 and 1962, respectively.

After serving as an intern at Passavant Memorial Hospital, Chicago, Illinois, from 1954 to 1955, he took his residency in the Northwestern University Neurosurgical Residency Program from 1955 to 1957, and from 1959 to 1961, a period interrupted by two years of service in the Air Force. In 1961, he was awarded a Postdoctoral Research Fellowship and also served as Clinical Assistant in Surgery at the Northwestern University School of Medicine. In 1962, he was appointed Director of Neurosurgical Education at Cook County Hospital, Chicago, Illinois. In 1963, he was appointed Associate Professor and Chairman of the Department of Neurosurgery, Marquette School of Medicine (now Medical College of Wisconsin), Milwaukee, and is currently Professor and Chairman of that Department.

Discussion

J. M. Van Name, (Philadelphia Electric Company Beryn, PA): The authors are to be commended for their extension of data into the area of high voltage experience. This complements that presented by C. F. Dalziel.

Recognizing I am not a medical doctor, the information presented is in such format that it can be interpreted by non-medical personnel. As a result of this, however, certain questions have been raised and perhaps the authors can comment on same.

1. Do you feel that the value is currently used for the resistance of a human versus animal should be revised from 1500 to 500 ohms, or to an even lower value?
2. Should the constant in Dalziel's shock formula that is related to weight be revised from 0.165 to 0.116?
3. Did the wire or conductor move (at all or violently) when the 14 kV tests were made?
4. Under Figure 2 it is noted that arcing occurred at the first 250 "ohms." Is this correct or is it within 250 "microseconds?"

Would the authors generally amplify their discussion based on the relationship between low voltage contacts (i.e., 110-220 volts) versus the high voltage contacts? This request is based on their extensive bibliography and studies in possible interrelationship of the two; they may thus be placed in better perspective. Indication by some readers may be that the higher the voltage the more serious the injury, when actually it is the current that produces a fatality, and the time frame included is in milliseconds.

Also, data on tire resistivity is essential in relating accidents to vehicle contacts. Some data exists in papers [1] and other data may be available.

REFERENCE

[1] Walter V. Inkis, "demonstrations To Public Of EHV Transmission Line Effects," vol. PAS-97, no. 2, March/April 1978, pp. 438-443.

Manuscript received February 25, 1980.

A. Sances, J. F. Szablya, J. D. Morgan, J. B. Myklebust and **S. J. Larson:**The pioneering works of Dalziel, Kouwenhoven and others have developed the basic physical mechanisms for contact with low voltages. This is fully discussed in reference 16. However, published works at higher potentials are not available. This investigation was therefore designed to determine the level of current which flows in living tissue following contact with distribution power lines. Further observations, such as the condition of the wire following contact, should be of value in the reconstruction of electrical accidents and for the design of protective devices for the amelioration of electrical trauma.

The results of this investigation show that the 500-1500 ohm values currently used to represent resistance are too high. Because of the thick, high impedance fat layer of the hog, the values obtained in this study are probably conservative. It is difficult to assign a specific value of resistance since it may vary with physical dimension of the contact. (Table 1, animal 1, P-H, experiment 6.)

Since it is the low levels of current which cause fibrillation while high levels routinely produce devastating burn injuries, no attempt was made to evaluate Dalziel's formula for fibrillation current. Although the animals routinely expired following forelimb to hindlimb contact, no conclusions regarding cardiac effects can be made.

For the voltage used, burn injuries are the predominant effect. Tissue destruction is proportional to the applied energy. Although more energy is available in high voltage contacts, the energy imparted depends upon the tissue metal interface impedance. Movement of the #2 ACSR wire was under the control of the operator.

Manuscript received April 8, 1980.