PIKE SOLAR LLC

Appendix AB- Electromagnetic Interference Report

ACADEMIC EVALUATION

OF

POWER-FREQUENCY

ELECTRIC AND MAGNETIC FIELDS

FOR THE

PIKE SOLAR ENERGY FACILITY

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NOTICE

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EXECUTIVE SUMMARY

The Pike Solar project includes a proposed 175 MW solar facility and 25 MW battery storage facility, scheduled for completion in 2023. Since the site is presently undeveloped and the project still in the planning phases, EMDEX LLC was retained by Pike Solar LLC and juwi, Inc. to perform an academic evaluation of the potential power-frequency (60 Hertz) electric and magnetic field levels which may be present at the completed project site. EMDEX LLC has conducted power-frequency electric and magnetic field spot measurements at eleven other solar facilities to characterize solar panels, inverters, transformers, substations, and overhead transmission lines which interconnect these solar facilities to the local electrical grid. EMDEX LLC has also measured four different battery storage facilities. Therefore, an academic evaluation was performed for the Pike Solar project based upon a summary of typical field levels around other solar facilities.

The following table presents a summary of the power-frequency electric and magnetic field levels measured at other facilities. As shown in this table, field levels along the perimeter of solar facilities are typically negligible (0.000 kV/m and 0.0 mG). Solar panels and underground collector cables only produce/carry direct current (DC) electricity, so there are no power-frequency electric or magnetic fields associated with solar panels or underground DC collector cables. Power inverters and transformers are housed within metallic housings which effectively grounds the power-frequency electric field outside of the housing. Magnetic fields can reach up to thousands of mG in close proximity to power inverters and transformers (within a few inches of the equipment). However, magnetic field levels decrease rapidly with distance away from this type of equipment and generally reach background levels at approximately 10 to 20 feet away from the equipment. Inverters and transformers are also generally located centrally within a solar facility and away from the perimeter. Alternating current (AC) collector cables are buried, allowing the earth to shield the power-frequency electric field. Magnetic fields can reach from tens up to hundreds of mG in close proximity above underground AC collector lines, but field levels again decrease rapidly with distance away from these cables. Substations and overhead AC power lines can be a significant source of power-frequency electric and magnetic fields at the perimeter of a solar facility, and field strength can vary based upon various facility parameters. Battery storage and charging facility equipment would have no power-frequency electric fields outside of the facility due to the shielding of internal sources by the building itself. Power-frequency magnetic fields should be very low outside of battery storage facilities, since magnetic fields decrease rapidly from internal equipment housed inside the building.

Note that solar facilities can be comprised of different equipment types and sizes, manufacturer makes and models, and have different rated output. Arrangement of solar panels, power equipment, and underground cables within an individual solar facility can also vary depending upon the design of the facility. Power output also varies based upon environmental conditions (i.e. sunny or cloudy days). Therefore, it is assumed that the Pike Solar project would be similar in design and layout to other typical solar facilities which have been previously measured and that the range of measured power-frequency electric and magnetic field levels would be comparable to those.

Presently, due to a lack of scientific evidence establishing health effects resulting from power-frequency electric and magnetic field exposure, there are no federal or Colorado state health-based standards for limiting exposure to those fields. However, exposure limits have been established or recommended by several different organizations. The guidelines and limits recommended by these organizations for power-frequency electric and magnetic fields are much higher than the measured levels encountered at the perimeter of the eleven solar facilities which were surveyed and internally at the four battery storage facilities.

Summary of Power-Frequency Electric and Magnetic Field Measurements Associated with Solar and Battery Storage Facilities[1]

Equipment/Location	Typical Measured Electric Field (kV/m)	Typical Measured Magnetic Field (mG)
Solar Facility Perimeter	0.000	0.0
Solar Arrays	0.000	0.0
DC Collector Cables	0.000	0.0
Inverter[2]	0.000 – 0.016	50 – 1131
Power Transformer[2]	0.000 – 0.016	50 – 3000+
AC Collector Cables	0.000	0.2 – 413
Substations	0.000 – 0.965	0.2 – 11.3
Overhead AC Power Line	0.225 – 1.811	0.1 – 27.5
Battery Storage Room (Internal)	0.000 – 0.011	0.5 – 213

1 – The measurement data provided in this table are based on EMDEX LLC survey measurements of eleven different solar facilities (ranging in output from 1.4 MW to 74.5 MW) and of four different battery storage facilities (internal measurements only).

2 – The upper end of the reported magnetic field measurement data for inverters and power transformers were measured in very close proximity to the equipment (usually within 1-inch of the housing). Magnetic field levels decrease rapidly with distance away from this type of equipment and generally reach background levels at approximately 10-20 feet away from the equipment.

INTRODUCTION

The Pike Solar project is a proposed 175 MW solar facility with a 25 MW battery storage facility. Energy can be stored in the battery system, which will be connected to both the solar facility and the power grid, allowing the solar facility to charge the batteries during daytime hours and discharge energy to the grid during more expensive peak hours or at night. The project is located in El Paso County, Colorado and scheduled for completion in 2023. Presently the site is undeveloped open land and the project is in the initial planning stages.

Since the site is presently undeveloped, field measurements cannot be performed to characterize power-frequency (60 Hz) electric and magnetic field levels from the project. However, EMDEX LLC has conducted power-frequency electric and magnetic field spot measurements at various other solar facilities, including field characterization of equipment such as solar panels, inverters, transformers, substations, and overhead transmission lines which interconnect these solar facilities to the local electrical grid. EMDEX LLC has also measured battery storage facilities. Therefore, an academic evaluation was performed for the Pike Solar project based upon a summary of typical field levels around various types of equipment from other solar facilities.

UNITS OF MEASURE

Magnetic fields are reported in units of gauss (G), or more typically in units of milliGauss (mG), which are equal to one-thousandth of a gauss (i.e., 1 mG = 0.001 G). Some technical reports also use the unit Tesla (T) or microTesla (µT; 1 µT = 0.000001 T) for magnetic field. The conversion between these units is 1 mG = 0.1 µT and 1 µT = 10 mG.

Electric fields are reported in units of volts per meter (V/m) or thousands of volts per meter (kV/m).

DESCRIPTION OF ELECTRIC AND MAGNETIC FIELDS

Electric and magnetic fields occur throughout nature and are one of the basic forces of nature. Any object with an electric charge on it has a voltage (potential) at its surface and can create an electric field. The change in voltage over distance is known as the electric field. When electrical charges move together (known as "current"), they create forces. These forces are represented by magnetic fields. All currents create magnetic fields.

The strength of electric and magnetic fields are related to the voltage and current respectively, and to the distance away from the source. The strength of the electric field depends on the voltage (higher voltages create higher electric fields) and the distance (electric fields grow weaker as the distance from the source increases). The strength of the magnetic field depends on the current or load (higher currents or loads create higher magnetic fields) and the distance (magnetic fields grow weaker as the distance from the source increases).

Static Electric and Magnetic Fields

Static (0 Hertz or Direct Current – 'DC') electric fields occur in nature. Static electric fields can result from taking off a sweater or walking across a carpet. The earth creates a natural static electric field of about 120 to 150 volts/meter (0.12 - 0.15 kV/m) at ground level due to the 300,000 to 400,000 volt potential difference between the ionosphere and the earth (Veimeister 1972). This means that a six-foot tall person would have a static potential of about 275 volts between the top and bottom of their body. Much stronger static electric potentials can exist underneath clouds, where the electric potential to earth can reach 10 to 100 million volts. Natural static electric fields under clouds and in some dust storms can reach 3 to 10 kV/m (CRC 1981). Static electric fields also result from friction when someone takes off a sweater, or walks across a carpet and then touches a doorknob. Body voltages as high as 16,000 volts (16 kV) have been measured on a person as a result of walking across a carpet (Chakravarti and Pontrelli 1976).

Static magnetic fields also occur in nature. The earth has a natural static magnetic field of about 540 mG in central Colorado (Merrill and McElhinney 1983). Static magnetic fields are also found very close to everyday objects such as refrigerator magnets. Many appliances utilize batteries or DC electricity (electric toothbrushes, electronic tablets, calculators, and other battery-powered devices).

Power-Frequency Electric and Magnetic Fields

Power-frequency (60 Hertz or Alternating Current – 'AC') electric fields are different from DC electric fields, since AC voltage alternates direction while DC fields have constant direction. The electric power distribution system, building electrical wiring, and electrical appliances create alternating electric fields. In the United States, the power system uses current that alternates 60 times each second (60 Hertz). Almost all household appliances create an electric field. This is due to the voltage on the appliance. To create an electric field, the appliance need not be operating, but just plugged into the wall socket. Typical reported values measured one foot away from some common household appliances are shown in Table 1 (Carstensen 1985, Enertech 1985).

However, electric fields can easily be shielded (or weakened) by conducting objects. For example, a typical house shields about 90 - 95 percent of electric fields from the outside sources (Deno and Silva 1987). Other grounded objects, such as trees, shrubs, walls, and fences, will also provide electric field shielding.

Power-frequency magnetic fields are created by the use of AC electricity (current flow). Sources of AC magnetic field include electric utility sources, as well as everyday household appliances. The magnetic fields under most transmission and distribution lines are usually smaller than values near many common household appliances. The main reason for this is the height above ground at which electric power lines are supported. Since the field decreases with distance away from the source, the line height above ground effectively reduces the magnetic field to levels that are less than many appliances. The magnetic field has been measured for numerous household appliances and typical values are given in Table 2 (IITRI 1984, Gauger 1985, Silva et. al. 1989).

Table 1. Typical Electric Field Values for Appliances (at 12-Inches Away)

Appliance	Electric Field (kV/m)
Electric Blanket	0.25*
Broiler	0.13
Refrigerator	0.06
Iron	0.06
Hand Mixer	0.05
Coffee Pot	0.03

* *Note:* 1 to 10 kV/m next to blanket wires
Source: Carstensen 1985; Enertech Consultants 1985

Table 2. Magnetic Fields from Household Appliances

Appliance	Magnetic Field at 12 inches Away (mG)	Maximum Magnetic Field (mG)
Electric Range	3 to 30	100 to 1,200
Electric Oven	2 to 25	10 to 50
Garbage Disposal	10 to 20	850 to 1,250
Refrigerator	0.3 to 3	4 to 15
Clothes Washer	2 to 30	10 to 400
Clothes Dryer	1 to 3	3 to 80
Coffee Maker	0.8 to 1	15 to 250
Toaster	0.6 to 8	70 to 150
Crock Pot	0.8 to 1	15 to 80
Iron	1 to 3	90 to 300
Can Opener	35 to 250	10,000 to 20,000
Blender, Popper, Processor	6 to 20	250 to 1,050
Vacuum Cleaner	20 to 200	2,000 to 8,000
Portable Heater	1 to 40	100 to 1,100
Fans/Blowers	0.4 to 40	20 to 300
Hair Dryer	1 to 70	60 to 20,000
Electric Shaver	1 to 100	150 to 15,000
Fluorescent Light Fixture	2 to 40	140 to 2,000
Fluorescent Desk Lamp	6 to 20	400 to 3,500
Circular Saws	10 to 250	2,000 to 10,000
Electric Drill	25 to 35	4,000 to 8,000

Source: IITRI 1984; Gauger 1985; Silva 1989

Unlike electric fields, most ordinary objects cannot easily shield magnetic fields. Many common materials (wood, air, concrete, earth, people, etc.) do not shield magnetic fields. However, ferromagnetic materials (such as iron or steel) or conductive materials (such as copper or aluminum) can shield them (EPRI 1999).

Power-Frequency Magnetic Field Studies

Two major research projects have been conducted to evaluate public exposure to ambient 60 Hz magnetic fields. This work was done to identify typical levels encountered by people inside homes and elsewhere. In the first study, a large number of residences located throughout the United States were measured to determine the sources and characteristics of residential magnetic fields (EPRI 1993). This project is called the "Thousand Home Study". During this study, spot (point-in-time) magnetic field measurements were taken in the rooms of almost 1,000 residences. Table 3 presents a summary of the study results. The average measured value for all rooms in this study was 0.9 mG. The Environmental Protection Agency also reports that background magnetic fields in American homes range from 0.5 mG to 4 mG (EPA 1992).

Table 3. Summary of Spot Room Measurements in the United States (992 Residences) - mG

Values Exceeded in:	All Rooms Median	All Rooms Average	Kitchen	Bedroom(s)	Highest Room *
50% of Residences	0.5	0.6	0.7	0.5	1.1
25% of Residences	1.0	1.1	1.2	1.0	2.1
10% of Residences	1.7	2.1	2.4	2.0	3.8
5% of Residences	2.6	3.0	3.5	2.9	5.6
1% of Residences	5.8	6.6	6.4	7.7	12.2

* *NOTE* - Any room in which spot field measurement had the highest value
Source: EPRI 1993

Another comprehensive study (the "Thousand Person Study") of magnetic field personal exposure was performed for the U.S. Department of Energy (DOE 1998). The objective of this study was to characterize personal magnetic field exposure of the general population. This study was accomplished by randomly selecting over 1,000 people located throughout the United States and recruiting these people to wear a recording magnetic field meter during a typical 24-hour period, including all activity inside and away from the place of residence. The study population was selected in a manner to be representative of the general population. The measurement population (both genders) included about 874 adults and 138 children. Table 4 presents a summary of average magnetic field exposures as a percentage of the U.S. population. People can experience a wide range of magnetic field exposures and sources, and the key findings from the study include:

- The U.S. 24-hour average for all people in this study was 1.25 mG
- Most of the population was exposed to less than 1 mG for a 24-hour average field
- Almost no gender difference in 24-hour average exposures
- About 14.3% of the U.S. population is exposed to a 24-hour average exceeding 2 mG
- About 25% of the U.S. population spend more than one hour in fields greater than 4 mG
- About 9% of the U.S. population spend more than one hour in fields greater than 8 mG
- About 1.6% of the U.S. population experience at least 1,000 mG during a 24-hour period

Table 4. Percentage of U.S. Population with Average Field Exposure Exceeding Given Values (Based on 1998 Population of 267 Million)

Average 24-Hour Field	Est. Portion	95% Confidence Interval	1998 Population Range	Extrapolated 2020 Population Range [1]
> 0.5 mG	76.3%	73.8 % - 78.9 %	197 - 211 million	244 - 261 million
> 1 mG	43.6%	41 % - 46.5 %	109 - 124 million	136 - 154 million
> 2 mG	14.3%	11.9 % - 17.2 %	31.8 - 45.9 million	39 - 57 million
> 3 mG	6.3%	4.8 % - 8.3 %	12.8 - 22.2 million	15.9 – 27.5 million
> 4 mG	3.35%	2.4 % - 4.7 %	6.4 - 12.5 million	7.9 – 15.6 million
> 5 mG	2.42%	1.67 % - 3.52 %	4.5 - 9.4 million	5.5 – 11.7 million
> 10 mG	0.43%	0.21 % - 0.90 %	0.56 - 2.4 million	0.69 - 3.0 million
> 15 mG	0.1%	0.02 % - 0.55 %	50 thousand - 1.5 million	66.2 thousand - 1.8 million

Source: DOE 1998

1 – Extrapolated 2015 U.S. population based on 331 million people

DESCRIPTION OF PHOTOVOLTAIC SOLAR FACILITIES

Pike Solar Facility Description

The Pike Solar project is a proposed 175 MW solar facility with a 25 MW battery storage facility. Energy can be stored in the battery system, which will be connected to both the solar facility and the power grid, allowing the solar facility to charge the batteries during daytime hours and discharge energy to the grid during more expensive peak hours or at night. The project is located in El Paso County, Colorado and scheduled for completion in 2023. Presently the site is undeveloped open land and the project is in the initial planning stages.

General Description of a Photovoltaic Solar Facility

A photovoltaic solar facility utilizes solar panels, interconnection cables, inverters, and power transformers to generate electrical power. DC electrical power is created by the solar panels, which is carried by underground interconnection cables to an inverter. The inverter converts DC electrical power to AC electrical power. A power transformer then converts low-voltage AC electrical power to high-voltage power. AC power is then carried by underground cables or overhead power lines to a nearby substation, where the electricity is supplied to the local electrical grid. Figure 1 presents a diagram of typical solar facility equipment and the generation process.

Utility equipment before the inverter (solar panels and interconnection cables) utilizes DC electricity rather than AC, so no power-frequency (AC) electric or magnetic fields are created by this equipment. The inverter, power transformer, and the underground cables or overhead power lines which carry AC electrical power to the nearby substation will create power-frequency electric and magnetic fields (as will the substation and associated power lines).

Typically solar facility equipment which are capable of producing power-frequency electric and magnetic fields are centrally located within the solar facility site and away from the perimeter of the facility. Solar panels are usually grouped together in sections (or “blocks”), with each section (or “block”) having an inverter and transformer located within that specific section. Underground cables then route AC power from the transformer at each section (or “block”) to a common connection point, which is usually a small substation. The substation and associated overhead or underground power lines which connect to the local grid are typically the only equipment located near the perimeter of a solar facility which produce power-frequency electric and magnetic fields (as shown in Figure 2).

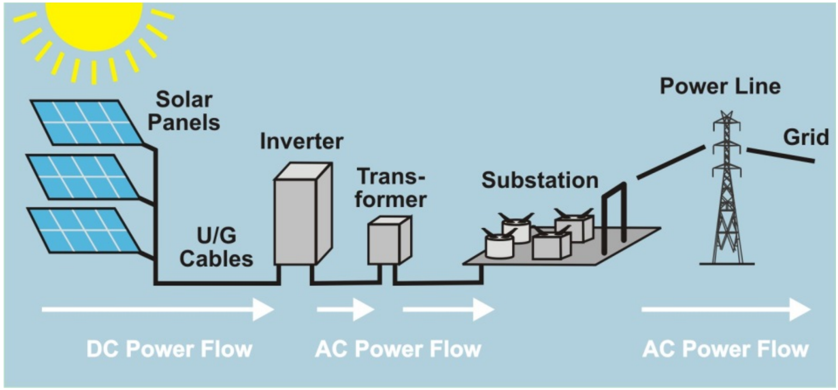

Figure 1. DC & AC Power Flow for a Typical Solar Facility

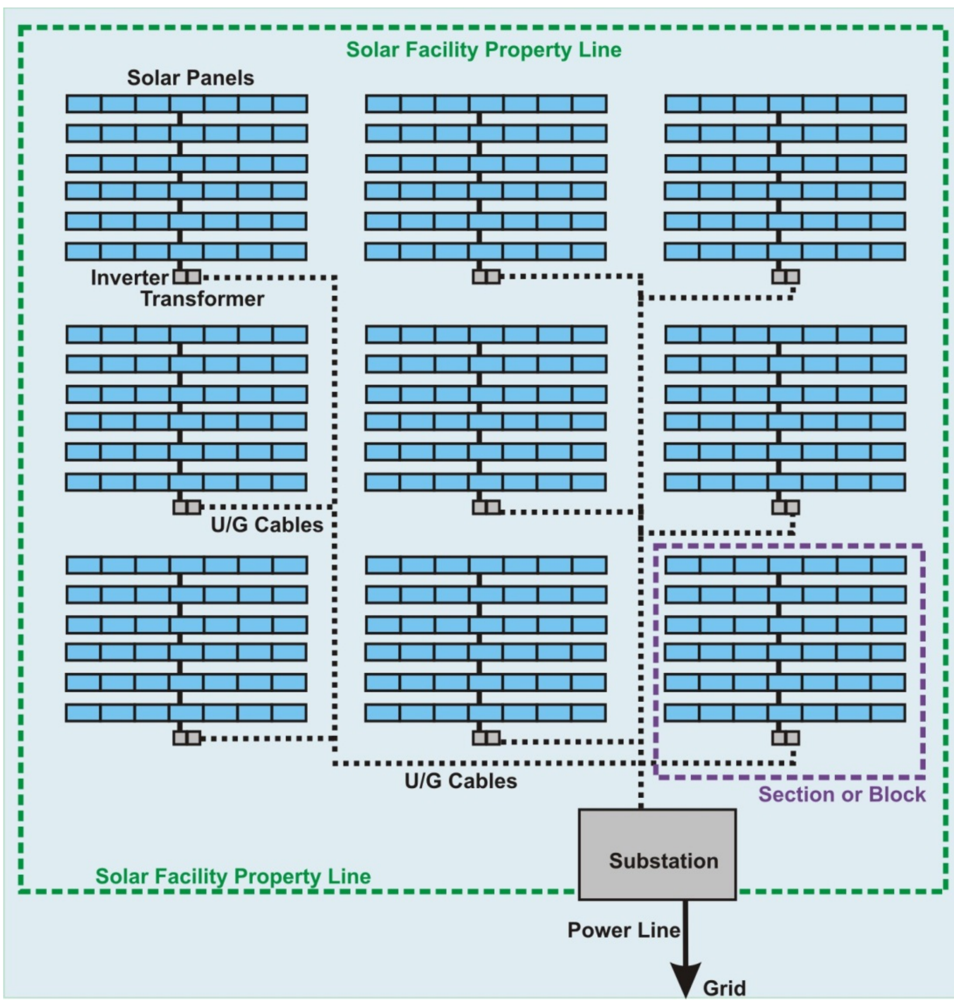

Figure 2. Main Components of a Typical Solar Facility (showing an individual section or block)

MEASUREMENT DATA FROM OTHER FACILITIES

Since the Pike Solar site is presently undeveloped, field measurements cannot be performed to characterize power-frequency (60 Hz) electric and magnetic field levels from the project. However, EMDEX LLC has conducted power-frequency electric and magnetic field spot measurements at eleven other solar facilities within the United States. These solar facilities ranged in size and overall capacity from 1.4 MW to 74.5 MW. Measurements included field characterization of equipment such as solar panels, inverters, transformers, substations, and overhead transmission lines which interconnect these solar facilities to the local electrical grid.

Note that solar facilities can be comprised of different equipment types and sizes, manufacturer makes and models, and have different rated output depending upon the number of solar panels per section (or “block”). Arrangement of solar panels, power equipment, and underground cables within an individual solar facility can also vary depending upon the design of the facility. Power output also varies based upon environmental conditions (i.e. sunny or cloudy days). Therefore, it is assumed that the Pike Solar project would be similar in design and layout to other typical solar facilities which have been previously measured and that the range of measured power-frequency electric and magnetic field levels would be comparable to those.

Perimeter of Solar Facilities

Power-frequency electric field measurements at the perimeter of the eleven solar facilities surveyed were 0.000 kV/m, and magnetic field levels were 0.0 mG (with one measurement reaching up to 1.0 mG due to the presence of other nearby external AC electrical equipment). Since solar facility equipment is typically located centrally within the solar facility site, there are usually no power-frequency electric and magnetic fields along the perimeter of a solar facility.

Solar Panels

Power-frequency electric field measurements near solar panels were 0.000 kV/m, and magnetic field levels were 0.0 mG (with some measurements reaching up to a few tenths of mG [0.5 mG] due to other nearby AC electrical equipment [typically underground AC collector lines]). Since solar panels utilize sunlight to produce DC electricity, there are no power-frequency electric or magnetic fields associated with solar panels.

DC Collector Cables

Power-frequency electric field measurements near underground DC collector cables were 0.000 kV/m. In addition to only carrying DC electricity, the earth shields any electric fields produced by underground cables. For power-frequency magnetic field, measured levels were 0.0 mG (with some measurements reaching up to tens of mG [11.0 mG] due to the routing of DC collector cables near AC underground collector cables). Since underground DC collector cables only carry DC electricity, there are no power-frequency electric or magnetic fields associated with underground DC collector cables.

Inverters

Power invertors are housed within metallic housings which effectively grounds the power-frequency electric field outside of the housing. Measured electric field levels were about 0.000 to 0.016 kV/m (0 – 16 V/m) in very close proximity to power inverters (within a few inches of the equipment) and diminish quickly with distance away from the inverter. Measured magnetic fields can reach up to thousands of mG (up to 1131 mG) in close proximity to power inverters (within a few inches of the equipment). However, magnetic field levels decrease rapidly with distance away from the inverter. At approximately 2-feet from the invertor, measured magnetic fields decreased to a range of about 25 mG to 200 mG depending upon the location of the measurement with respect to the invertor. At approximately 10 to 20 feet and farther away from the inverter, magnetic fields were further reduced to minimal background levels.

Power Transformers

Similar to inverters, power transformers are housed within metallic housings which effectively grounds the power-frequency electric field outside of the housing. Measured electric field levels were about 0.000 to 0.016 kV/m (0 – 16 V/m) in very close proximity to power transformers (within a few inches of the equipment) and diminish quickly with distance away from the inverter. Measured magnetic fields can reach up to thousands of mG (over 3000 mG) in close proximity to power inverters (within a few inches of the equipment). However, magnetic field levels decrease rapidly with distance away from the transformer. Similar to inverters, measured magnetic fields decreased to background levels at approximately 10 to 20 feet and farther away from the transformer.

Power transformers have also been characterized outside of solar facilities, such as in residential neighborhoods and shopping centers. For example, an Electric Power Research Institute (EPRI) report states that "in real world environments and other public locations where secondary magnetic field sources are typically present, magnetic fields from pad-mounted distribution transformers and other similar equipment attenuate as a function between one over the distance (1/r) and one over the distance squared ($1/r^2$)" (EPRI 2009).

AC Collector Cables

Power-frequency electric field measurements near underground AC collector cables were 0.000 kV/m. The earth shields any electric fields produced by underground cables. For power-frequency magnetic field, magnetic field levels will depend upon the amount of AC current flowing in the cables and the depth at which the cables are buried. Measured levels ranged from a few tenths of a mG (0.2 mG) up to several hundred mG (412.8 mG). However, magnetic field levels decrease rapidly with distance away from underground cables as well, and measured magnetic fields decreased to background levels at approximately 10 to 20 feet and farther away from the underground AC collector cables.

Substations

Substations can vary in their power-frequency electric and magnetic field characteristics, since substations can range in size, be comprised of different equipment types and sizes, manufacturer makes and models, and have different rated output. As with solar facilities, typically electrical equipment is centrally located within the substation site and away from the perimeter of the facility. Therefore, the overhead (and/or underground) AC power lines which connect into the substation are the dominant sources of power-frequency electric and magnetic fields at the perimeter of a substation.

Power-frequency electric and magnetic fields near substations can vary. For the substations associated with the eleven solar facilities evaluated, measured electric fields ranged from 0.000 kV/m to 0.965 kV/m. Usually a chain link fence or wall encloses the substation for security purposes, and this enclosure also shields the electric field within close proximity to the perimeter. For the substations associated with the eleven solar facilities evaluated, measured magnetic fields ranged from 0.2 mG to 11.3 mG. Measured field levels were higher at perimeter locations where the power lines enter and exit the substation.

Overhead AC Power Lines

Overhead AC transmission lines connect the solar facility to a nearby substation, or if the substation is present as part of the solar facility (as shown in Figure 2), then overhead AC transmission lines provide interconnection to the local electrical grid. Electric and magnetic fields from overhead power lines can vary greatly, depending upon a number of different power line parameters (arrangement/phasing of the conductors, number of conductors per phase, line voltage and current, distance between phases and/or other circuits, height of the conductors above ground level, and other various parameters).

For the eleven solar facilities evaluated, measured electric fields associated with these overhead power lines ranged from ranged from 0.225 kV/m to 1.811 kV/m. Measured magnetic fields ranged from 0.1 mG to 27.5 mG.

Battery Storage Facilities

EMDEX LLC has conducted field measurements at several battery storage facilities (although none associated with a solar facility, battery storage facilities are typically similar in design across different electrical generation facilities). For this evaluation, field measurements were performed internally at four battery storage/charging facilities (two associated with a hydro-generation facility, one at a distribution substation, and one at a large generating station). For these facilities, measured electric fields ranged from 0.000 kV/m to 0.011 kV/m while measured magnetic fields ranged from 0.4 mG to 213 mG. These measurements were conducted inside of the battery storage room themselves (near the charging equipment). Field levels would quickly diminish with distance away from the equipment and would be much lower at a location external to the battery storage/charging facility. For electric fields, the facility walls would shield the electric field outside of the facility.

POWER-FREQUENCY ELECTRIC AND MAGNETIC FIELD STANDARDS

Presently, due to a lack of scientific evidence establishing health effects resulting from power-frequency electric and magnetic field exposure, there are no federal or Colorado state health-based standards for limiting exposure to those fields. However, exposure limits have been established or recommended by several different organizations. These address both electrical field and magnetic field exposure for a variety of conditions, and in some cases, exposure limits for workers with implanted medical devices.

In the "Threshold Limit Values" published by the American Conference of Governmental Industrial Hygienists (ACGIH 2012), recommended occupational exposures should not exceed 25 kV/m for AC electric fields and 10,000 mG for AC magnetic fields. Above 15 kV/m, the ACGIH recommends the use of protective clothing. For workers with cardiac pacemakers, recommended exposures should not exceed 1 kV/m for AC electric fields and 1,000 mG for AC magnetic fields. Table 5 presents a summary of the ACGIH guidelines for AC electric and magnetic fields.

Some implanted medical device manufacturers have also reported recommendations for their equipment which are comparable to the ACGIH limits for magnetic fields and higher limits for electric fields (for example, 6 kV/m for 60 Hz electric fields and 1 Gauss for 60 Hz magnetic fields).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP 2010) has also developed guidelines for AC electric and magnetic fields. Table 6 presents a summary of the ICNIRP guidelines for AC electric and magnetic fields.

The International Committee on Electromagnetic Safety, which is a committee under the Institute of Electrical and Electronics Engineers (IEEE), has also provided recommendations for electric and magnetic fields. These recommendations are specified for both the general public and in controlled environments.[1] Table 7 presents a summary of the IEEE guidelines for AC electric and magnetic fields (ICES 2002).

The guidelines and limits recommended by these organizations for power-frequency electric and magnetic fields are much higher than the measured levels encountered at the eleven solar facilities which were surveyed and at the four battery storage and charging facilities.

[1] Controlled Environment is defined by the IEEE as "An area that is accessible to those who are aware of the potential for exposure as a concomitant of employment, to individuals cognizant of exposure and potential adverse effects, or where exposure is the incidental result of passage through areas posted with warnings, or where the environment is not accessible to the general public and those individuals having access are aware of the potential for adverse effects." (IEEE 2002)

Table 5. ACGIH – Occupational Threshold Limit for 60-Hertz Electric and Magnetic Field Exposure

Exposure	AC Electric Field	AC Magnetic Field
Occupational exposures should not exceed	25 kV/m (from 0 Hz to 100 Hz)	10 Gauss (10,000 mG)
For workers with cardiac pacemakers or similar medical electronic devices, maintain exposure at or below	1 kV/m (1,000 V/m)	1 Gauss (1,000 mG)

Table 6. ICNIRP – Reference Levels for Time-Varying 60-Hertz Electric and Magnetic Fields

Exposure (60 Hz)	Electric Field	Magnetic Field
Occupational	8.333 kV/m (8,333 V/m)	10 G (10,000 mG)
General public	4.167 kV/m (4,167 V/m)	2 G (2,000 mG)

Reference levels are intended to be spatially distributed over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded.

Table 7. IEEE – AC Electric and Magnetic Field Maximum Permissible Exposure

Exposure (60 Hz)	Electric Field	Magnetic Field
General public	5 kV/m (5,000 V/m) [a,d] (from 1 Hz to 368 Hz) [c]	9.04 G (9,040 mG) (from 20 Hz to 759 Hz)
Controlled environment	20 kV/m (20,000 V/m) [b,e] (from 1 Hz to 272 Hz) [c]	27.1 G (27,100 mG) (from 20 Hz to 759 Hz)

a – Within power line rights-of-way, the MPE for the general public is 10 kV/m under normal load conditions.

b – Painful discharges are readily encountered at 20 kV/m and are possible at 5 – 10 kV/m without protective measures.

c – Limits below 1 Hz are not less than those specified at 1 Hz.

d – At 5 kV/m induced spark discharges will be painful to approximately 7% of adults (well-insulated individual touching ground).

e – The limit of 20,000 V/m may be exceeded in the controlled environment when a worker is not within reach of a grounded conducting object. A specific limit is not provided for this standard.

SUMMARY AND CONCLUSIONS

The Pike Solar project includes a proposed 175 MW solar facility and 25 MW battery storage facility, scheduled for completion in 2023. Since the site is presently undeveloped and the project still in the planning phases, EMDEX LLC was retained by Pike Solar LLC and juwi, Inc. to perform an academic evaluation of the potential power-frequency (60 Hertz) electric and magnetic field levels which may be present at the completed project site. EMDEX LLC has conducted power-frequency electric and magnetic field spot measurements at eleven other solar facilities to characterize solar panels, inverters, transformers, substations, and overhead transmission lines which interconnect these solar facilities to the local electrical grid. EMDEX LLC has also measured four different battery storage facilities. Therefore, an academic evaluation was performed for the Pike Solar project based upon a summary of typical field levels around other solar facilities.

The following table presents a summary of the power-frequency electric and magnetic field levels measured at other facilities. As shown in this table, field levels along the perimeter of solar facilities are typically negligible (0.000 kV/m and 0.0 mG). Solar panels and underground collector cables only produce/carry direct current (DC) electricity, so there are no power-frequency electric or magnetic fields associated with solar panels or underground DC collector cables. Power inverters and transformers are housed within metallic housings which effectively grounds the power-frequency electric field outside of the housing. Magnetic fields can reach up to thousands of mG in close proximity to power inverters and transformers (within a few inches of the equipment). However, magnetic field levels decrease rapidly with distance away from this type of equipment and generally reach background levels at approximately 10 to 20 feet away from the equipment. Inverters and transformers are also generally located centrally within a solar facility and away from the perimeter. Alternating current (AC) collector cables are buried, allowing the earth to shield the power-frequency electric field. Magnetic fields can reach from tens up to hundreds of mG in close proximity above underground AC collector lines, but field levels again decrease rapidly with distance away from these cables. Substations and overhead AC power lines can be a significant source of power-frequency electric and magnetic fields at the perimeter of a solar facility, and field strength can vary based upon various facility parameters. Battery storage and charging facility equipment would have no power-frequency electric fields outside of the facility due to the shielding of internal sources by the building itself. Power-frequency magnetic fields should be very low outside of battery storage and charging facilities, since magnetic fields decrease rapidly from the internal equipment which is housed inside the building.

Note that solar facilities can be comprised of different equipment types and sizes, manufacturer makes and models, and have different rated output. Arrangement of solar panels, power equipment, and underground cables within an individual solar facility can also vary depending upon the design of the facility. Power output also varies based upon environmental conditions (i.e. sunny or cloudy days). Therefore, it is assumed that the Pike Solar project would be similar in design and layout to other typical solar facilities which have been previously measured and that the range of measured power-frequency electric and magnetic field levels would be comparable to those.

Presently, due to a lack of scientific evidence establishing health effects resulting from power-frequency electric and magnetic field exposure, there are no federal or Colorado state health-based standards for limiting exposure to those fields. However, exposure limits have been established or recommended by several different organizations. The guidelines and limits recommended by these organizations for power-frequency electric and magnetic fields are much higher than the measured levels encountered at the perimeter of the eleven solar facilities which were surveyed and internally at the four battery storage facilities.

Summary of Power-Frequency Electric and Magnetic Field Measurements Associated with Solar and Battery Storage Facilities[1]

Equipment/Location	Typical Measured Electric Field (kV/m)	Typical Measured Magnetic Field (mG)
Solar Facility Perimeter	0.000	0.0
Solar Arrays	0.000	0.0
DC Collector Cables	0.000	0.0
Inverter[2]	0.000 – 0.016	50 – 1131
Power Transformer[2]	0.000 – 0.016	50 – 3000+
AC Collector Cables	0.000	0.2 – 413
Substations	0.000 – 0.965	0.2 – 11.3
Overhead AC Power Line	0.225 – 1.811	0.1 – 27.5
Battery Storage Room (Internal)	0.000 – 0.011	0.5 – 213

1 – The measurement data provided in this table are based on EMDEX LLC survey measurements of eleven different solar facilities (ranging in output from 1.4 MW to 74.5 MW) and of four different battery storage facilities (internal measurements only).

2 – The upper end of the reported magnetic field measurement data for inverters and power transformers were measured in very close proximity to the equipment (usually within 1-inch of the housing). Magnetic field levels decrease rapidly with distance away from this type of equipment and generally reach background levels at approximately 10-20 feet away from the equipment.

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