Standard Scientific Research and Essays Vol1 (14): 391-397, December (ISSN: 2310-7502)
http://www.standresjournals.org/journals/SSRE

Research Article

Construction Issues Faced By Renewable Energy Production Facilities – Solar PV Farms in Ontario, Canada

Kibriya T

Black and Veatch Corporation, KS, USA

Author E-mail: t_kibriya@yahoo.com

Accepted 28 November 2013

Abstract

Wind and solar farms have come up to be popular sources of renewable energy in many parts of the world, in addition to other renewable energy sources. The province of Ontario in Canada has turned out to be one of the most popular locations for setting up renewable energy farms because of its strong initiatives for sustainable policies and development along with attractive rates offered for renewable energy through Ontario Hydro's popular Feed in Tariff (FIT) Programme. In addition to wind, numerous Solar PV Farms have been completed; many are under construction while still more are in planning and permitting stage in this province, varying from 3MW to up to 260MW located in the suburbs of cities and towns which are being benefited from these renewable energy sources. Winter conditions and extreme frost in certain areas in Ontario poses unique issues with construction of such farms. Typical construction comprises of solar PV panels mounted on racking tables supported on foundations usually comprising of partially embedded steel pipes while foundations for I-Houses, E-Houses, transformer foundations and substation structures are either concrete pads or piles. While the substation structures, I-House and E-House foundations have well defined design procedures regulated by different codes and standards, the procedures, codes and standards for design and testing of lightly loaded solar PV structures still need to be formulated. In the absence of any specific codes and standards regulating the design aspects of these lightly loaded solar PV structures with frost uplift being the governing load in almost every case for Ontario, Canada, frost heaving and its effects often create adverse conditions for these structures thereby affecting the production and continuous supply of renewable energy to the cities and towns in vicinity who purchase this energy. This study investigates these unique issues related with renewable energy farms which are presented in this paper. The author has been involved in design/design reviews, pile selection/ design and pile load testing in the majority of the solar PV farms either operational or under construction in Ontario along with being involved with the rehabilitation of solar PV farms affected by pile heaving issues.

Keywords: Renewable Energy, Solar PV, Racking Foundation, Panel Tables, Solar Panels

INTRODUCTION

An important concept of achieving sustainability is through the production and use of renewable energy. Wind and solar farms have come up to be popular sources of renewable energy in many parts of the world along with other renewable energy sources. The province of Ontario in Canada has turned out to be one of the popular locations for setting up renewable energy farms because of its strong initiatives for sustainable policies and development along with attractive rates offered for renewable energy through Ontario Hydro's popular Feed in Tariff (FIT) Programme. In addition to wind, numerous Solar PV Farms have been completed; many are under construction while still more are in planning and permitting stage in this province, varying from 3MW to up to 260MW located in the suburbs of cities and towns which are being benefited from these renewable energy sources. These solar PV farms, usually commissioned/contracted for 20/25 years are fully recycled at the close of contract since almost every component of these farms is recyclable.

Severe winters and extreme frost in certain areas in Ontario poses unique issues with construction of such farms. Typical construction comprises of solar PV panels mounted on racking tables supported on foundations usually comprising of partially embedded steel pipes while foundations for I-Houses, E-Houses, transformer foundations and substation structures are either concrete pads or piles. While the substation structures, I-House and E-House foundations have well defined design procedures regulated by different codes and standards, the procedures, codes and standards for design and testing of these lightly loaded solar PV structures still need to be formulated. In the absence of any specific codes and standards regulating the design aspects of the solar PV structures and frost uplift being the governing load in almost every case for Ontario, Canada, frost heaving and its effects may create adverse conditions for these structures thereby affecting the production and continuous supply of renewable energy to the cities and towns in vicinity which purchase this energy. In the absence of specific codes and standards regulating the design aspects of the solar PV structures, differences usually erupt between EPC contractors and designers on design and testing of these foundations pile structures. This study investigates these unique issues related with such foundations in extreme weather conditions with frost being a major issue which are presented in this paper.

Layout of Typical Solar PV Farm

General layout of a solar PV farm is in the form of rows of panels connected through wires which take the DC generated through combiner boxes to inverter houses where inverters convert DC to AC. This AC is passed through step up transformers to raise the voltages suitable to be fed to the main utility lines to which the output is to be fed through a switching control and metering system. Suitable panel types with varying capacities from 77watts to 350watts are oriented in portrait or landscape orientations in various combinations of 2 to 4 panel heights in rows of racking supported on racking foundations. Fixed racking is common in Ontario with very few farms with sun trackers installed to move racking to face sun during the day.

Typical Foundations used for solar panels/ racking and governing loads

Typical foundations for the panel tables comprise of various types of steel piles like steel pipes, screw piles, helical piles, and steel piles jacketed in concrete through the embedment depth. Ballast supported racking is usual for very soft soils/ landfill sites. These piles may be fully driven into soil or pre-drilled in hard soils and areas with boulders/cobbles and rock. Under reamed piles with concreted base are solutions for areas where sufficient resistance to uplift cannot be provided by straight piles but is slightly expensive as compared to straight pile options and are difficult to be installed in sandy soils without additional measures. Due to the large amount of piles, typically around 5000 piles for a 10MW solar PV farm, EPC contractors prefer steel piles, whether plain, screws or helical, which can be installed quickly since usual duration to complete a 10MW (usual size of farms being built in Ontario) is around 18 to 24 weeks including commissioning. In most cases, 2.75m to 3.5m embedment of 114mm to 125mm diameter steel pipes in dense granular and clayey soils usually produce the desired uplift resistance with or without 200mm diameter concrete jacketing usually carried out around the embedment depth. In case bedrock is available in near depth, the piles are anchored in bedrock through rock sockets which provide sufficient resistance against uplift. Most helicals and screw piles with similar shaft sizes of around 114mm to 125mm diameters are commonly used in solar industry.

Most of the racking manufacturing companies get the racking design through wind tunnel tests. The reactions on the foundation piles are obtained through the wind tunnel tests. The unfactored pile loads for these foundation piles range typically from 45kN to 60kN of compression, 8kN to 14kN of lateral, 15kN to 24kN of wind (up/down) and 5kN to 9kN of dead loads in Ontario while frost loads vary from 45kN to 76kN for 114mm outer diameter of the shaft of piles being used at most of the sites in Ontario, based on correct interpretation of frost depths. Typical values for adfreeze pressures are average values taken from Canadian Foundation Engineering Manual for steel and concrete.

Understanding frost penetration under Solar PV panel Tables

Correct interpretation of frost is an important factor in design of foundation piles since frost loads are the governing loads in this region. For few of the farms where pile foundations moved out under the effects of frost after first few winters, it revealed in investigations that a lower frost penetration depth was considered for design of the foundation piles embedment on the mere assumption that snow accumulation in the area will result in a lower frost penetration depth whereas the actual situation observed in the field was totally different. Due to the inclined shape of panel table structure, practically there is almost zero to very little snow accumulation around the piles observed even in severe winter snowfall conditions allowing greater frost penetration depths around foundation piles as shown in Figure 1. 100% piles for these sites had to be remediated from frost effects since all the piles installed at this site did not anchor below the maximum depth of frost. Figure 2 below shows a solar panel foundation pile moved out due to frost effects after the first severe winter. There were other farms too where a large percentage of piles were affected by frost and had to be remediated since they were also built with the assumption of snow accumulation leading to reduced frost penetration.

Figure 1. Typical row of solar panels in winter showing very little to no snow accumulation around foundation piles.

Understanding adfreeze stress values

For design adfreeze pressures, typical values are taken from Canadian Foundation Engineering Manual [1]. Typical values given for steel and concrete are 100KPa for contact with steel and 65KPa for contact with concrete. Understanding the magnitude of adfreeze stresses is generally lacking. While the

Figure 2. A pile moving out due to frost

Canadian Foundation Engineering Manual clearly indicates that the adfreeze pressure values suggested are average values, EPC contractors and some consultants generally argue these pressures to be the ultimate. TM5-852-4 of the US Army and Air Force [2] indicates that the adfreeze stresses may be as high as 276KPa before the initial break in bond between frozen soil and pipe in tests carried out on an 8” pipe tested in frozen silty soils. Sailors Engineering Associates [3] carried out laboratory testing on samples of small diameter pipes with and without application of Slick coat friction reduction Epoxy. These tests also measured adfreeze pressures of up to 296KPa on steel pipes. The SEA Report states that the adfreeze pressures of up to 296KPa exist just before the initial bond break between the frozen soil and steel pipe and hence it is assumed that the adfreeze pressures given by Canadian Foundation Engineering Manual are average residual pressures after the initial bond break between the frozen soil and the steel pipe. This clearly indicates that peak adfreeze forces acting on the piles can be much higher than the average values given by the Canadian Foundation Engineering Manual.

Effects of lack of quality/ testing on life cycle of piles and effects of pile heaving

Testing of deep foundations is governed by ASTM 3689 [4] for axial tensile testing, ASTM 1143 [5] for axial compression testing and ASTM 3966 [6] for lateral testing of piles. The foundation piles for such facilities are not designed based on the soil geotechnical characteristics but are selected based on the pile load tests carried out in the area they are to be installed. When it comes to testing foundation piles for solar farms where a large numbers of piles are to be installed, these standards do not provide definitive guidelines on numbers of piles to be tested for design testing or production testing although they do layout a very detailed procedure on methodology of carrying out the testing itself and its procedures and measurements to be taken along with failure criteria. The various testing methods given in these standards also do not differentiate between design testing and production testing. These aspects always pose a problem for the designer to specify an appropriate number of pile load tests which should be carried out on site to confirm the capacity of the piles. While most EPC contractors tend to go with as little as one/two pile load tests for design verification with few only willing to carry out 6 to 8 pile load tests for design verification for the entire farm, usually 10MW capacity with typically around 5000 piles to be installed. This reluctance by the EPC contractors is merely on the grounds that the solar panel support structures are not life threatening structures and any movement is of little consequence if it occurs. Most EPC contractors did understand the consequences when they were explained the possible effects of moving out of piles uniformly/differentially which could make electrical wires taut and break the connection between panel tables, combiner boxes can be damaged with damaged wires due to frost heave effects, additional stresses can be induced in racking beams to damage them while large movement can damage the panels too due to distortion , all of which can result into loss of production along with rehabilitation effort and expenses involved. Figure 3 below shows some of these effects in the solar panel tables due to frost heaving of some piles.

Figure 3. Piles affected by frost showing deformation of the racking

To maintain the quality of construction on site and to ensure that the piles are going to perform satisfactorily throughout the site, it is essential that a number of piles are installed and subjected to design load testing throughout the area with minimal failure rate. Keeping in view the large number of piles to be installed, an appropriate number of piles usually suggested to be tested are 1% of the total piles installed although the percentage can be raised up to 100% for trouble soils. Another way of controlling this issue is to specify a failure rate like 0.5% to 1% for the entire site which is being adopted by few owners of such farms being built now. ANSI ASQ Z1.4 [8] is a good reference since it provides sufficient guidelines and tables to interpret the sample size and failure rate of the piles over the entire site. Canadian Foundation Engineering Manual [1] guidelines are extremely useful in this context since it suggests that piles must be tested up to twice the design load and preferably up to failure for design stage load testing.

Ambiguity on Factor of safety on frost load in load testing.

Frost loads are not the governing loads for building structures, hence are not given to be factored in the present building codes. Frost loads are the governing loads for these lightly loaded panel support structures. Most EPC contractors are reluctant to add any Factor of Safety to design load i.e. the frost load for pile load testing and in most cases, the argument given is that frost is a serviceability load. Hence they tend to install the test piles and test them to 100% of frost loads only.

It is worthwhile to understand that to maintain quality and ensure that 100% of piles perform as designed on sites where large numbers of piles (say 5000 piles for a 10MW facility) are to be installed, there has to be a Factor of Safety added to the governing load case or a reduction factor applied to the soil resistance, otherwise the mere variation in soil and other pile installation inadequacies in the field may not provide the desirable quality of foundations. The Canadian Foundation Engineering Manual [1] suggests a geotechnical factor of 0.4 in tension for design of piles through static pile load tests since all the piles for solar farms are designed based on frost loads. This geotechnical factor provides a Factor of Safety of 2.5 in the design. Most EPC contractors are extremely reluctant to this Factor of Safety and submit argument that it is too un-conservative for the solar panel foundations. Usually they suggest an Factor of Safety of 1.5 based on considering it to be live load. Most piles for the load tests are fully driven into undisturbed soil and load tested. The pull out capacity of these piles is then compared with the design frost loads. By doing this, the skin friction of the effective frost depth zone is thereby also included in the pile resistance. To accurately assess the capacity of the embedment of the pile below the frost zone, it is better to pre-drill to the frost depth of the pile, install the pile with design embedment depth below the frost zone and test these piles for their capacity to hold against the frost uplift forces. Alternately, skin friction of the pile surface through the frost depth needs to be estimated/calculated and added to the frost loads for comparison with the pull out capacity of the piles, for an accurate capacity assessment of the test pile.

Typical Pile Test Results for Various Soil Conditions

To save on costs and time, typically the piles to be installed in the solar farms are tested by the EPC contractors mainly for uplift since the design is governed by frost adfreeze forces which are usually somewhat higher than the compressive loads, in addition to limited lateral testing. Usually EPC contractors are reluctant to carry out compressive testing on piles and a usual argument given is that if the tensile resistance of the piles is larger than the compressive loads, the pile is good for the compressive loads too. This argument comes from the fact that soil resistance in tension is usually lower than in compression and has been tested to be right in most cases. In the presence of bedrock, piles anchored in rock sockets are usual and provide sufficient uplift resistance. Helical piles have shown good resistance to uplift in soils depending upon the helix size and thickness but are difficult to install in the presence of boulders and cobbles in the sub grade while screw piles performance in dense soils requires slightly larger embedment depths for required uplift resistance.

One of the techniques followed by screw pile companies for installing screw piles in areas with bedrock and soil with gravel/cobbles/boulders is to pre-drill a hole slightly larger than the diameter of the screw (150mm for a 122mm diameter screw), backfill the hole partially with gravel in the bottom portion of the pile embedment, below the frost zone, and install the screw pile with the design torque. This technique did not perform very well in providing the required uplift resistance in many cases and many such screws failed in the field in Ontario. Few of such failing screw piles, when retrieved after load tests were seen to have their screws sheared off from the shafts. Larger lengths of such screws did provide better uplift resistances. However, when the same screw piles were installed in pre-drilled holes slightly smaller than the screw sizes (89mm for 122mm diameter of screw) without any gravel backfill, the screws were observed to perform better.

Pile installation in loose silty soils with ground water seepage has been a difficult proposal. Larger embedment depths of screw piles and helicals may work if the qualities of soil at greater depths are better. Concreting around the piles in such areas provides larger contact areas in addition to slight increase in the dead loads which can increase the resistance of the piles to bear the uplift loads, however larger depths of embedment have to be resorted to. Sloughing and caving of the sides in the case of pre-drilling in such areas are usual issues along with curing of concrete in the presence of ground water seepage. Ground water must be pumped out from the pre-drilled holes before concreting otherwise segregation of mortar and aggregates is likely in case the concrete is poured on seepage water inside the pile holes. Tremie method is advisable for concreting in the presence of water. Figure 4 shows a typical pile in soft silty soil where the pile bottom got buried some depth below in soft soil due to which full embedment depth could not be concreted. Figure 5 shows a typical pull out failure of piles in soft soils where adequate uplift resistance could not be provided.

Rehabilitation works and Frost mitigation techniques

Foundation piles at few solar PV farms were affected by frost in the very early service life with some of them experiencing frost heave issues during the first winter after their commissioning. Figures 2 and 3 above show the piles moving out due to frost effects in the first winter of their service life. Rehabilitation

Figure 4. Pile moved into soft soil before concreting

Figure 5. Pile failure in uplift in load testing in soft soils

Works on piles which have moved out under the effects of frost fall mainly in two categories:-

Short Term Measures

In the short term rehabilitation measures, the piles which have moved out beyond tolerances due to frost heave have to be pushed back to their original position. Pushing back piles is a tedious issue since it requires panel tables fixed on top of the foundation piles to be removed which involves switching off of few circuits resulting into production losses. Some solar PV farms constructed earlier and facing frost heaving issues with piles had to resort to this sort of rehabilitation since many piles at these sites moved out by 75mm to over 100mm (mostly differentially) thereby exerting additional stresses on the racking, distortion on the panels and tension on the connecting wires. To overcome this issue of pushing back the piles without having to remove the panels, few contractors developed some kind of extension to be connected to the backhoe or hydraulic pile driver by the help of which the piles can be pushed back to their original position without having to remove the panels. This development has saved loss of production at few of the sites facing pile heaving issues due to frost

Long Term Measures

Addition of dead load to the pile to overcome frost loads

Addition of dead load on the piles equivalent to the frost adfreeze force can prevent the effects of frost on the piles.

Strengthen existing piles by replacing with longer piles

Increasing length of piles embedment beyond the frost depth increases the resistance of the piles to pull out hence preventing them from any frost uplift effects.

Installing additional piles adjacent to existing piles

In case strengthening of existing piles is not possible, another way of strengthening them is to drive another pile adjacent to the existing pile and connect both the piles for added resistance.

Under reaming and concreting.

Rehabilitation of existing piles through under reaming and adding concrete at the base to improve their up lift capacity is another way of strengthening the piles. In this process, soil around the existing piles is removed, concrete is added at the base and the soil is backfilled and compacted.

Restrict frost penetration around the piles by insulation

It is a common practice to restrict frost penetration by extending the insulation equal to the maximum frost depth in the area, around the building floor slabs resting on soil. Similar methodology is followed for restricting the frost penetration in the soil around the foundation piles. Using the methodology of insulation design around the buildings, a width of insulation equal to the maximum depth of frost penetration is designed for appropriate thickness according to the maximum freezing degree days from graphs given in certain books [1, 2] and is laid around each pile at an appropriate depth, usually 300mm. The insulation is covered by a layer of soil above to protect it. This step reduces the frost penetration around the piles thereby reducing or eliminating the effects of frost.

Adding frost sleeves to existing piles.

Use of sleeves around the piles through the frost zone helps the frozen soil around the pile move freely without exerting any uplift forces on the piles. Such methods are extensively followed in permafrost regions [9]. Sonotube, PVC or HDPE sleeves wrapped in two to three layers of polyethylene with a layer of lubricant like petroleum jelly/ grease between the layers and is applied to the piles through the frost depth typically to prevent any adfreeze forces from acting on the piles thereby preventing any affects from frost.

CONCLUSION

Solar PV Farms are a great source of renewable energy to the towns and suburbs in which they are located. By following the best engineering practices, these Solar PV Farms can be erected with minimal effort in short durations and do not usually have large maintenance issues throughout their service life, except minimal maintenance or change of major parts like inverters and transformers, on completion of their design life. Every component of these solar PV farms is recyclable at the end of their contract period. Over the years, most EPC contractors have become more experienced having faced issues at some of the earlier constructed solar PV farms along with most designers too and quality of construction is improving with the understanding of the issues involved. Rapid construction and commissioning of these farms along with minimal maintenance, low running costs and better rates offered by Ontario government under its FIT Programme have largely increased the interest of large investment houses and financial companies in this sector due to which a large number of such renewable energy facilities have come up while many more are in the development stage in various regions of Ontario in Canada.

References

[1] Canadian Geotechnical Society(2006). *Canadian Foundation Engineering Manual*, 4th Edition.
[2] Department of Army and Air Force(1983).TM5-852-4, *Arctic and Sub Arctic Construction - Foundations for Structures*, October.
[3] Sailors Engineering Associates, *Adfreeze Bond Reduction by Slick coat Friction Reduction Epoxy Coating*, Georgia, USA
[4] ASTM(2007). D3689, *Standard Test Methods for Deep Foundations under Static Axial Tensile Load*.
[5] ASTM(2007). D1143, *Standard Test Methods for Deep Foundations under Static Axial Compressive Load*.
[6] ASTM(2007). D3966, *Standard Test Methods for Deep Foundations under Lateral Load*.
[7] Kibriya T (2013).*Racking Foundation Piles Design and Testing Review Report for Various Solar PV Farms in Ontario*.
[8] ANSI(2003). ASQ Z1.4 *Sampling Procedures and Tables for Inspection by Attributes*.
[9] Permafrost Technology Foundation, *Design Manual for New Foundations on Permafrost*, September 2000.