FEASIBILITY STUDY OF APPLICATION OF DSSC IN DISTRIBUTION NETWORKS

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ABSTRACT

This paper presents a feasibility study of the application of distributed static series compensator (DSSC) in 11 kV distribution networks. The study investigates the mechanical stability of feeders, cross arms and poles in the presence of the DSSC devices. In addition, the extra tension applied to the wires by the weight of the device has been calculated for different types of overhead lines in different operating conditions. The results indicate that most of the existing distribution feeders have the capability to withstand the extra mechanical load represented by the suspension of the DSSC devices from the lines.

1 INTRODUCTION

Distributed Static Series Compensation (DSSC) is a concept which can be used to alter the effective reactance of a line and help to control power and reactive power flows in an electrical network. The idea was first introduced in 2007 by Deepak et. al. to alter the reactance of transmission lines [1]. The application of DSSC in distribution networks was later discussed in [2]. As well as power flow control, DSSC can be employed to enhance the performance of the distribution network by managing the voltage profile along feeders [3]. It must be noted here that static series compensation can also be provided by large synchronous static series compensation (SSSC) devices. However, when considering a distribution network, the optimal size and location of such a device can be a difficult problem and events leading to network reconfiguration can significantly affect the efficiency and effectiveness of SSSC devices [4]. The distributed nature of DSSC can overcome these shortcomings and deliver better performance than conventional SSSC devices whose performance is severely dependent on network structure.

The proposed DSSC approach is presented in Fig. 1. The figure shows part of a radial 11 kV overhead line distribution feeder fed by a distribution substation. The line is shown supplying a residential and industrial area separately. The feasibility of the application of DSSC devices in terms of mechanical failure of the feeder as a result of the extra weight of the devices has not been studied in the literature. In this paper the mechanical capability of the existing overhead lines to withstand the additional load represented by the DSSC modules is investigated. It is assumed that there are three DSSC devices between two poles and each of the three single-phase devices is suspended from a different phase. In this study, various design considerations are considered including line vibrations, conductor tension and cross arm design.

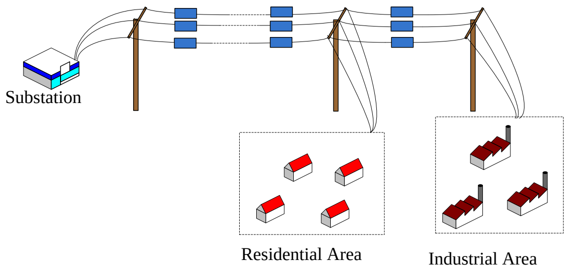

Figure 1: Application of DSSC in electrical distribution networks

2 OVERHEAD LINE DESIGN CONSIDERATION

The mechanical construction of an overhead line, and its maintenance, requires a lot of attention in the design process of the line. Generally the most likely element to fail in an overhead line is the conductor and this can happen because of high winds or overloading of the line due to ice. For example, most of the reported overhead line failures in 11kV distribution circuits are related to line breakages [5]. Long spans increase the possibility of conductor clashing and may cause some damage at the contact points. This will weaken the strength of the wires and increase the likelihood of a break down in windy or bad weather conditions. For these reasons, care must be taken to ensure that the extra weight presented by the suspension of DSSC devises from the line conductors is fully taken into account when considering the application of DSSC.

2.1 Restricted vibration

Vibrations in an overhead distribution line can be divided into two categories. The first is an oscillation with a large amplitude and low frequency referred to as Galloping and is generated by winds with speed of 5-10 miles/s. This type of vibration usually occurs in locations with long spans, for example where lines cross rivers or highways. The second type is referred to as Aeolian vibrations and is a vertical vibration with low amplitude and normally with the frequency of about the natural frequency of the line.

With regard to the Galloping, the suspension of DSSC from existing lines acts like added inertia and will initially contribute toward damping of any small amplitude weak oscillations in the line. However, as the large amplitude oscillation starts, for example as a result of strong wind, the extra weight of the DSSC device will boost the oscillation and may lead to a clash between the lines.

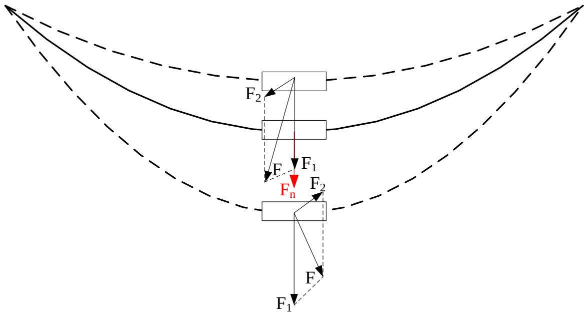

Figure 2: Decomposition of mechanical forces

The decomposition of mechanical forces in a DSSC compensated line is shown in Fig. 2. In the figure, F is a mechanical force pointing toward the ground due to the mass of the line and the DSSC device. Under normal conditions, i.e. no oscillation, F_2 is zero and F_1 is equal to F. However, as the line moves to the side as a result of Galloping F will be decomposed into the two orthogonal forces F_1 and F_2 with F_2 trying to force a return back to the pervious conductor location. Thus, and in accordance with Newton laws of motion, it may be concluded that the extra mass of the DSSC device will help stop the initialisation of Galloping. However if as result of strong winds Galloping is initiated, the extra mass means that it may become more difficult to stop. Therefore where there is a likelihood of Galloping, in areas like river or highways crossings, the installation of DSSC is not recommended in those sections of the line. Because of the distributed nature of the compensation, however, this will have a minimal effect on the performance of the line as a whole.

Aeolian vibration on the other hand is not directly related to the weight of the wire and will not be significantly affected by the presence of DSSC devices in the power lines. This kind of vibration is caused by continuous wind and the margin for this movement is similar to the wire dimensions.

2.2 Conductor tension

Conductor tension is generated by the line mechanical load which is a combination of wind force and weight of the conductor. The former is mainly horizontal and is referred to as the Maximum Conductor Pressure (MCP), while the latter is a vertical load and is referred to as the Maximum Conductor Weight (MCW). The maximum permissible tension of the conductor is the tension which the conductor can stand at a temperature of –5.6°C, considering the effects of all loads including wind pressure and weight. The maximum tension of the conductor must of course be within certain safety limits. The suspension of DSSC modules, however, means that there is a possibility of the resultant tension exceeding the existing safety margins as a result of the extra weight of the modules.

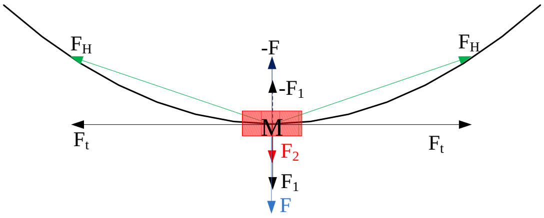

Figure 3: Interaction between the forces in line with DSSC

Fig. 3 shows the forces generated by the mass of the line, the mass of the DSSC module and the forces generated in the line to counter the resultant force. In the figure, F_2 is generated by the mass of the DSSC module and is equal to $m_D g$, where m_D is the mass of the DSSC device and g is the gravitational acceleration. F_1 represents the force generated by the mass of the line and is equal to $m_l g$ where m_l is the mass of the line section between two poles. F is the sum of the two forces F_1 and F_2. In order to counter the effect of F, the line generates the force F_H, which may be decomposed into two orthogonal components, –F and F_t, as shown. The force –F has exactly the same magnitude as F but acts in the opposite direction while F_t is the force which creates tension in the wire. The line tension will therefore increase with any increase in F. For this reason the effects of adding the external weigh represented by the DSSC modules must be carefully studied.

The tension withstand capability of a power overhead line varies from line to line depending on the dimensions, materials and geometry of the wires. The characteristics of Aluminium alloy, as a commonly used conductor for 11kV overhead lines, is selected for investigation in this study. A conductor with a cross sectional area of 180.7 mm^2 has a mass of approximately 497 kg per km, with a calculated breaking load of 50.65 kN [6]. Assuming that each DSSC module has a mass of approximately 50 kg and considering the mass of 0.4 km section of the line (the maximum span length for medium class poles) then the wire must be able to withstand (0.4*497+50) kg. The force produced by such a mass is around 2.4kN and is less than the calculated breaking load for the wire. So, in this case suspension of DSSC modules from the wire may not be problematic in terms of the calculated breaking load. Using another example of a standard aluminum alloy stranded conductor (with a cross sectional area of 30.10 mm^2 and an approximate mass of 82 kg/km) the calculated breaking load is 8.44 kN. By adding the weight of the DSSC device, the total load will be 82.8 kg which produces a force of 0.8 kN, still less than the breaking load of the conductor.

However, as the cross sectional area of the wire becomes smaller the ratio of breaking load to the resultant load becomes smaller and care must be exercised when considering the implications of DSSC.

4. CROSS-ARM DESIGN

Cross-arms on top of the overhead line poles in distribution feeders are used to hold the line conductors and the related insulators. In terms of their mechanical design, the cross-arms must be able to support two different types of vertical and horizontal loads. Vertical loads include the weight of the wire and an extra load of about 225 lb [7] which is the approximate weight of a line worker. The horizontal load is generated mainly by wind. Wire tension in most cases is negligible because the generated tensions from both sides of the cross-arm are equal. Generally, both vertical and horizontal loads depend on the characteristics of the conductor, the span, ice load and wind load. The vertical load can be calculated [7] as follows:

$$T_v = [W_w + 0.913 * \pi * i\ (i + d)10^{-3}] \tag{1}$$

In equation (1) T_v is the vertical load on the cross-arm (Fig. 4), while i and d represent the cross section of ice load and wire, respectively. W_w is the weight of wire and this will be increased by the additional weight of the DSSC modules. This will increase T_v for each cross-arm but the new load should not cause any immediate problems since the mass of the DSSC device (at less than 50 kg) is less than the extra design weight margin representing the weight of a line worker. The many varieties of cross-arm designs as well as different quality of the materials used in their construction are key parameters that must be carefully considered before the inclusion of DSSC modules in distribution feeders. As discussed earlier they have some margins to with stand extra load but this cannot be generalized for all networks Because the weight margins can be different from one cross-arm design to another, it is recommended that each circuit should be investigated individually on a case by case basis in order to obtain a certain level of confidence, safety and reliability.

The horizontal load will be different for cross-arms which are located through the feeder from those which are at the begging or at the end of the feeder. For a cross-arm not located at either ends of the line (Fig. 5), the horizontal load is calculated [7] as follow:

$$T_{t_1} = (P_w * d * 10^{-3})S_w \tag{2}$$

where T_{t1} (kg) is the horizontal force of wind and P_w (k/m^2) is the wind pressure. d represents the cross sectional diameter of the wire and S_w is the effective length of the span. The additional weight of a DSSC module does not affect any of these parameters. Therefore, no extra horizontal load is imposed by the suspension of the DSSC modules.

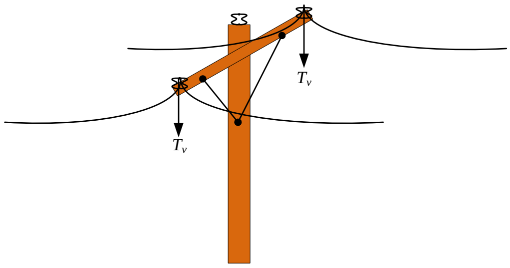

Figure 4: Vertical load on cross-arm

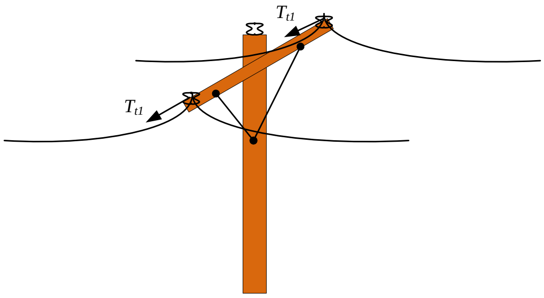

Figure 5: Horizontal load on cross-arm

However, at locations where there is a bend in the feeder an additional force due to the angle of the bend is added to the horizontal load of the cross-arm. In this case, the resultant force is the combination of wind force and the angle force and can be calculated [7] as follows:

$$T_{t_2} = 2HSin\frac{}{2} + (P_w * d * 10^{-3}) * S_w \tag{3}$$

where T_{t2} is the resultant horizontal force and H is horizontal tension in the line. In this equation, H can be affected by the weight of the DSSC modules. This may be mitigated by using supportive joints, etc. However, because of the distributed nature of DSSC, the connection of DSSC modules in such sensitive locations can simply be omitted.

A similar situation can be found at the beginning or at the end of the feeder. At these locations, the line tension on the two sides of the cross-arm is not equal. Normally, the line tension from the substation side is negligible and the total horizontal force is the combination of two orthogonal forces, one generated by the wind and the other generated by the line tension in the direction of the conductor. These forces are shown in Fig. 6.

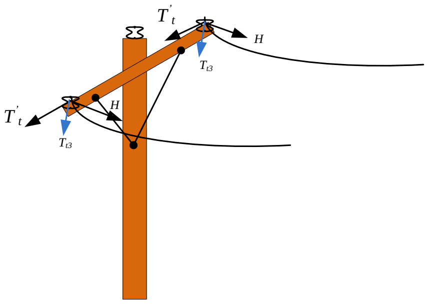

Figure 6: Horizontal cross-arm loads at the two ends of the line

In this situation, the total load, T_{t3}, is calculated [7] as follows:

$$T_{t3} = \sqrt{H^2 + T_t'^2} \quad (4)$$

In this equation T_t' as discussed earlier cannot be affected by the weight of the DSSC device, however, H must be considered. If the inclusion of a DSSC module at the beginning or at the end of the feeder becomes necessary for any reason, then the cross-arm must be supported mechanically by a supportive structure.

Two other parameters must be considered in the cross-arm design process, the phase to phase distance and the phase to pole distance. The phase to pole distance is the minimum space between the closest wire to the pole or its connection and can be calculated [7] as follows:

$$L_{min} = 125 + 5 * (V - 8.7) \quad (5)$$

where L_{min} (mm) is the minimum distance between line and pole and V is the line voltage. For example, for an 11kV feeder this must be at least 136.5 mm, however other issues such as birds sitting on the wires or maintenance requirements mean that this distance is larger in practice. In equation (5) L_{min} is function of V only, and is not affected by the additional weight of the DSSC modules. So, it can be stated that series compensation of a line using DSSC will not change the minimum distance required between pole and line. The minimum distance between two phases PC (needed to make sure that they are electrically isolated) is calculated [7] as follows:

$$PC = K_e\sqrt{f_{max}} + L_I + \frac{V}{150} \quad (6)$$

where V is the line voltage and L_I represents the insulator string length. In this equation the maximum depth of span is represented by f_{max} and K_e is a parameter which is determined by type of wire, its material and cross sectional area. These parameters are not going to be affected by suspending the DSSC modules from the line. However, it is recommended that the modules are connected to the three conductors in different locations between each two adjacent poles. The suggested configuration is shown in Fig. 7.

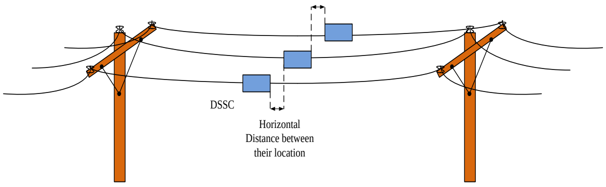

Figure 7: Connection of DSSC modules in different locations

5. CONCLUSIONS

The suspension of DSSC modules from phase conductors will increase the inertia of the wire and this will have an effect on the horizontal oscillations of the wires as well as increasing the tension in the wires. The strength of the conductors must therefore be carefully checked before suspending the modules in order to make sure that the new arrangement is mechanically sound. The extra weigh of the modules can also generate an extra force on the pole cross-arms. The installation of DSSC modules is therefore not recommended in sensitive locations such as bends, corners or road and river crossings where the pole span is high.

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