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PETERSEN COILS - BASIC PROPERTIES AND CONDITIONS FOR A (STANDARD) CENTRAL OR DECENTRALIZED SOLUTION

SAŽETAK

Sve veći opseg distribucijskih mreža, a posebno porast udjela kabelskih vodova navodi mnoge distribucijske tvrtke na razmatranje budućeg razvoja sustava za kompenzaciju kapacitivnih struja zemljospoja (rezonantno uzemljenje). Za mreže s uobičajenom topologijom koju čini veći broj usporedivih vodova s ravnomjerno raspodijeljenim kapacitetom vodova prema zemlji, najbolje dokazana središnja kompenzacija je osigurana u glavnoj trafostanici mreže. Korištenje samo ove metode postupno dovodi do značajnog povećanja snage prigušnice za suzbijanje luka (ASC, Petersenova prigušnica) u zvjezdištu transformatora napajanja ili do paralelnog spajanja dodatnih prigušnica. U nekim slučajevima ovo povećanje snage može doći do granica dimenzioniranja zvjezdišta.

Međutim, povećanje kapacitivnih struja u mrežama obično je uzrokovano kabliranjem "gušćih" dijelova mreže napajanih iz nekoliko vodova. Rezonantno uzemljenje takvog kabelskog područja tada se može povoljno riješiti decentralizirano, tj. s zasebnom Petersenovom prigušnicom. Kada se napajanje ovog dijela mreže prebaci s jedne trafostanice na drugu, čini se da je područje kompenzirano i nije potrebno povećavati snagu središnjih svitaka u trafostanicama za napajanje.

U članku se obrađuju osnovne značajke rada središnje i decentralizirane kompenzacije kapacitivnih struja u zemlji, navode se prednosti i slabosti različitih rješenja, uključujući njihov utjecaj na funkciju zemljospojne zaštite i indikatora u odvodima iz trafostanica.

Ključne riječi: prigušnica za gašenje luka, Petersenova prigušnica, zvjezdište, centralna kompenzacija, decentralizirana kompenzacija

SUMMARY

The ever-increasing scope of distribution networks and especially increase in share of cable lines leads many distribution companies to consider the future development of systems for compensation of earth fault capacitive currents (resonant earthing). For networks with the usual topology formed by a larger number of comparable lines with uniformly distributed line capacity to ground, the most proven central compensation is provided in the main power substation of the network. Using only this method gradually leads to a significant increase in the power of the Arc Suppressing Coil (ASC, Petersen coil) in the star-point of the supply power transformer or to connect additional coils in parallel. In some cases, this increase in power can run into limits of the star-point dimensioning. However, the increase in capacitive currents in networks is usually caused by the cabling of "denser" parts of the network fed from a few lines. Resonant earthing of such a cable area can then be advantageously solved decentralized, i.e. with a separate Petersen coil. When the power supply of this part of network is switched from one substation to

another, the area then appears to be compensated and it is not necessary to increase the power of the central coils in the supplying power substations.The article deals with the basic operating characteristics of central and decentralized compensation of earth capacitive currents, the strengths and weaknesses of various solutions are mentioned, including their influence on the function of earth fault protections and indicators in the feeders from the substations.

Key words: Arc suppresion coil, Petersen coil, star-point operation, central compensation, decentralized compensation

1. INTRODUCTION

Just as Europe consists of many countries, the power systems have also been developed in different ways. Depending on the country, there are various voltage levels of the distribution networks and also several types of neutral point treatment.

1.1. Neutral point treatment

The distribution network is possible to operate in several ways that are determined by method of grounding. Each method has its own advantages and disadvantages. The most significant difference is network behaviour during the earth fault: possibility of fault self-extinguishing, earth fault current value, overvoltage and possibility of network permanent operation during the earth fault.

It is obvious that the method of neutral point earthing affects the reliability of power supply, safety during an earth fault and of course the costs. The 4 main relevant methods used for neutral point grounding of multiphase electrical system are: Solidly grounded neutral point, resistance grounding, isolated neutral point and resonant earthing.

Resonant earthing is typical for all Central European countries, i.e. in addition to Poland, the Czech and Slovak Republics, all German-speaking countries, Scandinavian and Baltic countries, East Europe, Italy, but also Middle Asia or Israel. It brings many advantages in comparison with other methods of neutral point treatment. Arc suppression coil (ASC, Petersen coil) reduces earth fault current to minimum when kept properly tuned. Capacitive part of earth fault current is compensated by inductive current passing through the coil and the faulty point. So, in case of properly tuned coil the residual fault current is limited to minimum and has mainly active character. This is the main advantage of this system because of good conditions for self-extinguishing of the arc. Due to this self-extinguishing capability, about 80 % of all earth faults in overhead lines, which are transient earth faults, are cleared. In this case it is not necessary to interrupt power supply immeditatelly compared to the networks operated with different types of earthing mentioned above.

Remaining 20 % of all earth faults in overhead lines are permanent faults. The low value of the fault current enables to operate the network with a permanent earth fault, however, it is suggested not to operate the network for unnecessary long time. During operation with the earth fault, the phase voltage in sound phases has value of the line voltage and that is why there is higher risk of secondary cross country fault (double earth fault) occurrence.

2. PRINCIPLE OF RESONANT EARTHING

During the earth fault a capacitive current Ic flows from the sound phases through the phase-to-earth capacitances. The current flows via the faulty point back to the network. This capacitive current value depends on the line-to-earth capacitance. With increasing extent of distribution networks and especially with increase in share of cable lines it can reach high values (hundreds of Amperes). See figure 1.

The main principle of the earth fault current compensation is using an arc suppression coil producing compensation current of inductive character. The ASC is installed between the neutral point and earth and it is tuned to a specific inductance, that in case of solid earth fault produces the current with nearly the same magnitude like the capacitive earth fault current, but 180 degrees out-of-phase.

The inductance of the ASC and the earth capacitance of the network are in resonance for fundamental network frequency – that is why this method of neutral point treatment is called “resonant earthing”.

Because the reactive part of the fault current is very low in case of properly tuned ASC, through the fault point flows almost no reactive current of fundamental frequency. The residual current is then very low, usually about 2-5 % of capacitive charging current. In this case residual current is caused by insulation leakage and coil losses and it has active (resistive) character.

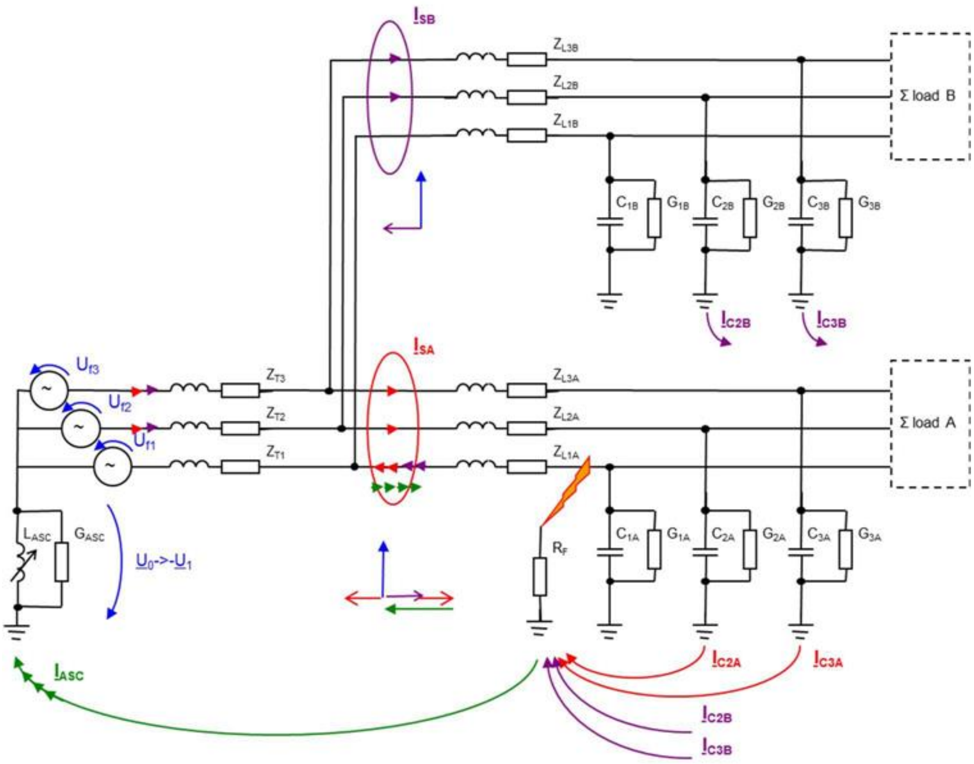

Figure 1: Principle of resonantly grounded networks

As written above, there is necessary to produce compensating inductive current and bring it to the neutral point of the network. It is possible to do it separately from more current sources (coils). Important is, that the sume of all this currents must correspond to the needed value. The coils whose currents are added up can be connected in parallel to one neutral point, but the injection point for the compensation current does not have to be just one, there can be several neutral points in one network.

3. NEUTRAL POINT(S)

3.1. Central neutral point of the power transformer

The standard way of arc suppression coil connection used in the distribution network is to connect it to the star point of supply transformer. This arrangement is the simplest in principle and is based on the premise that the MV distribution network is always connected via at least one transformer to the parent system. This assumption is practically always fulfilled, the exception being, for example, island operations of some industrial networks. The transformer connection and dimensioning must enable loading of its star point, i.e. the MV winding must be connected as a star and at least one other winding (usually tertiary) in the transformer must be delta connected. The delta winding is not necessary to be in this transformer when the MV side is connected as a broken star (Zig-Zag).

The disadvantage of this arrangement is the necessity to dimension the connected coil to the power required to compensate the entire phase-to-ground capacity of the MV network for both standard operating conditions and for conditions when a larger area of the MV distribution network could be connected through the transformer. This is for example the summer operation of substation with two transformers via a single supply transformer. In this case a neutral point busbar can be used to allow parallel operation of the coils installed in the substation. It can be considerably more complicated to provide the necessary compensation power in case of a shutdown of the entire transformer on the HV side. In this case it is necessary to take over the supply of the MV network by another substation, including providing of the compensation power (ASC). Usually, the partitioning of the distribution network between the surrounding substations must be solved not only in terms of the required power supplied, but also in terms of compensation phase-to-ground capacitive current.

3.2. Artificial central neutral point in the main substation

Another possibility is to use also centralised neutral point in the main supply substation but created by the earthing transformer. Such an artificial neutral point can be formed by grounding transformer, as seen in the figure 2. Neutral point created by grounding transformer is also preferred in the networks where the HV/MV power transformer does not have a properly dimensioned neutral point or the tertiary delta winding. It is not necessary to change expensive HV transformer for ASC installation, it can be connected to the grounding transformer.

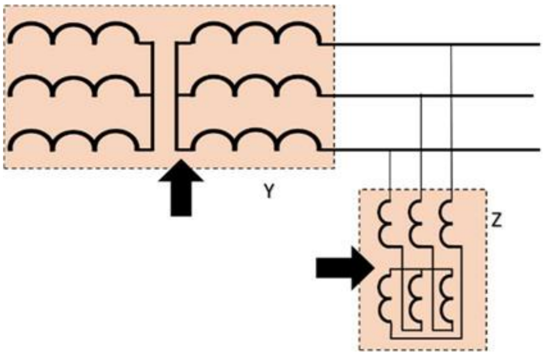

Figure 2: Neutral points

Usually Zig-Zag winding transformer is used for this purpose thanks to properties of this connection. This winding is connected to the MV busbar (phases of the network). In resonantly grounded networks neutral point of this transformer is then connected to an arc suppression coil, so the MV side of the transformer is dimensioned according to the power of ASC. This neutral point maker is a principally simple device that needs the same prepared foundation as standard transformers of similar size and weight. It is not even necessary for this device to be a real transformer (with a secondary winding) for the creation of the neutral point itself, then sometimes it is called a neutral point builder.

On the other hand, there is still the disadvantage of having to replace the earthing transformer if a new ASC is to be connected to it in parallel with the existing one or if the existing coil is to be replaced by a new one with a significantly higher power.

3.3. DECENTRALIZED NEUTRAL POINTS

Unlike the power transformer, the earthing transformer does not have to be installed in the main power station. Decentralized compensation may be advantageous for compensation of large network parts, that can be switched among the supplying systems or substations. Especially in case of significant network expansion by adding of cable lines or areas, it may be therefore preferable to choose decentralised compensation.

Artificial neutral point is than created by earthing transformer (or builder) connected to the grid in some switching station in the part of network where the earth capacitive current increased. Thanks to this it is not necessary in case of network expansion to replace the installed central arc suppression coil for increasing of compensation power, but there can be added another coil via earthing transformer.

Of course, the earthing system in this switching station must correspond to the requirements for protective earthing in stations with MV neutral point grounding. This is one of the reasons why some distribution network companies are not inclined to install many neutral point groundings in common distribution stations of the network. It is mainly used in switching stations supplying clearly defined network areas and equipped, for example, at least with remote monitoring and control.

When power supply of this area (inlets to the station with decentralized compensation) is switched to another system, either among systems within a substation or even to a different substation, there is no significant step change in the earth fault current compensation system in either of the affected networks.

If this switchover occurs in a fault-free condition, the time for which the networks are significantly detuned is minimized and the risk of high touch voltages and high value of faulty current in case of an earth fault in the period before the ASCs in both networks are tuned is reduced.

If the part of the network is switched to another system (or switches it off) during the fault localization manipulations, the fault current will not be changed by a high step change caused by the detuning by the earth capacitive current of the switched part of network. This will significantly reduce the risk of touch voltage increase at the fault location and the risk of more damage is also limited.

4. COMBINED ARC SUPPRESSION COIL

Usually the earthing transformer and ASC are two separate devices, for which two foundations must be built, including sumps for oil leakage collecting, etc.

Due to the possibility of using a single stand and simpler installation, it seems to be more suitable to install a combined device consisting of an ASC and a suitably dimensioned earthing transformer. It spares the space and costs. The connection diagram and example of such a combined device is in the figure 3.

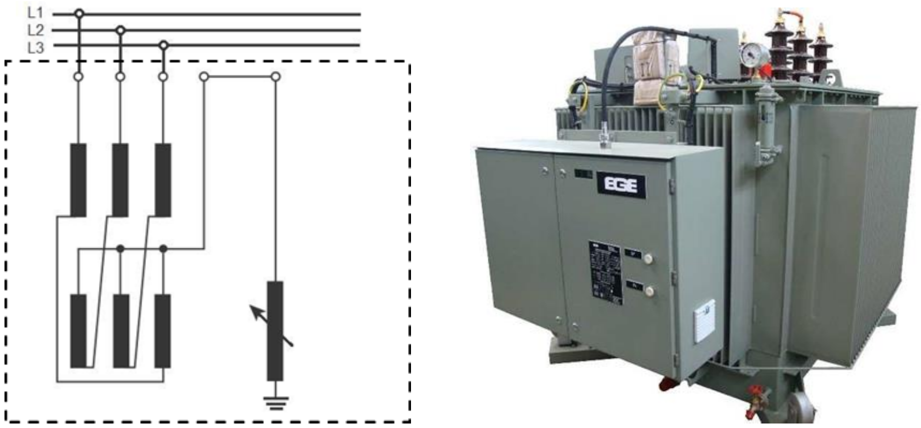

Figure 3: Combined acr suppression coil without secondary winding

In addition, it is possible to design a grounding transformer with a secondary winding in ZNyn or ZNzn connection and use it for supplying the switching station's consumption. In this case the secondary LV winding is dimensioned according to the “transformation” power, usually low hundreds of kVA, but the primary MV winding and the magnetic circuit are dimensioned higher by the power necessary for ASC and its duty. So, the ASC and the primary winding of this transformer are dimensioned according to the operational standards of network operator, for example 2 hours short time duty under the earth fault conditions, but the whole device, especially the secondary winding is dimensioned for permanent load of the LV side.

5. TUNING

Tuning process of the combined arc suppression coil can vary based on wiring, coil type and operation. The simplest arc suppression coil has fixed value. This coil can’t be tuned and in normal distribution system, where the network can change sometimes, must be installed also tuneable coil. In this case tuning of the combined arc suppression coil is not an issue.

More practical solution is to use tuneable combined arc suppression coil. If the coil is the only coil in the network, tuning will work the same way as standard tuning process of the coil in the neutral point of HV/LV power transformer. Coil can be tuned by controller in automatic mode.

If the combined coil is supplement of the central ASC, then the tuning has to be processed in cooperation of both coils. If both coils are equipped by controllers and these controllers have parallel feature available, this functionality must be used. The central coil tunes the network if the network is changed and if the range of the coil is not sufficient and reach the maximal value, combined coil starts tuning too. This is the most sophisticated solution requiring interconnection of both controllers, which is often complicated especially when the combined coil is decentralized and installed in some switching station far from the main supplying power station.

More often the controller of combined coil is operated in a manual mode and the controller of the main central ASC in an automatic mode. The combined coil is pre-tuned to the current value corresponding to the scope of network part which is switched together with the coil. If it is needed to retune the combined coil due to a significant change in the scope of this sub-network into which it works, central controller will be set to manual mode and combined coil controller vice versa. It is also possible to pre-tune the combined coil manually and the central coil will tune the network more precise after that.

6. PROTECTIONS

Very important question is whether the functionality of earth fault detection and protection systems will not be negativelly affected when using the decentralized earth fault compensation. Generally it could not be this case, all the standard eath fault detection methods should work corectly even when decentralized resonant earthed neutral points are used in the line where the indicator is installed. The scope of influence depends on the detection methods.

Directional neutral overcurrent method, also called wattmetrical, is basic and mostly used in all earth fault protections and indicators. Its functionality could be influenced by changing the value of active part of zero sequence current of the line or substation feeder. Decentralized compensation can generally influence the value of this current, because of a certain part of this current is caused by active losses in arc suppression coil and when some coil is installed in the earth fault affected line, corresponding part of this active current does not flow from the central ASC and starpoint of power transformer through the current measuring transformers in the substation feeder. Decentralised earth fault compensation can also result in a certain reduction of the total damping and thus also of the active component of the earth fault current when it occurs in another part of the network. The reason is that the ground capacitive current is compensated decentralized and it will not flow through the lengthwise impedance of the the whole length of the lines from the transformer neutral point to the compensated network, the neutral point created by decentralized earthing transformer makes this loop shorter. Thus, there will be no additional voltage phase shift on the network phase-to-ground capacitance caused by the active resistance of the relatively long lines. It is very difficult to estimate this effect in advance, its degree depends also on the actual load of the network. According to different calculating models it can be expected that the active component of zero sequence current measured for directional overcurent protection will be reduced by maximum a few amperes in feeder in which also decentralised neutral point with earth fault compensation is used, and therefore the effect of the use of decentralized compensation can be considered insignificant for this earth fault detection method.

Influence on the transient detection methods is not to be expected, because the coil inductivity in the neutral point(s) does not play any important role for transient phenomenon at the moment of earth fault development. This is due to much higher frequency of this transient phenomenon than the network’s fundamental frequency.

A significant influence of decentralized compensation can be expected for ground fault detection methods based on the detection of higher harmonic components in the zero-sequence current. The weak point of these methods is the risk of false triggers in feeders, where a significant part of the cable network with a large earth capacitance is connected behind a long outdoor line, so the resonance frequency of the zero-sequence impedance of this line can fall into the range of harmonic components used for detection (usually the 5th, possibly even the 7th harmonic). In general, one can expect a reduction in the probability of this false triggers, because the partial compensation applied to the line will move its own resonance frequency away from the harmonics used for detection.

7. PRACTICAL EXAMPLE

Following example from the Czech Republic is an illustration of an appropriate use of the combined arc suppression coil in the real network. The map of the area can be seen in a figure 4.

The urban area is currently supplied by cable network with the voltage 10 kV from the substation 35/10 kV. This substation is connected thanks to the 35 kV lines with 3 substations 110/35 kV. These supplying substations are equipped with tuneable arc suppression coils for compensation of earth fault current of the existing networks.

But in these days, the city cable network (10 kV) is being converted to 35 kV voltage. The transformer 35/10 kV will be removed, and the network will be connected directly to the rest of 35 kV network. In relation to the rest of the network, a new network part with earth capacitive current IC > 50 A will be therefore created. Since this urban cable network can be supplied from 3 different locations, it is necessary to ensure sufficient capacity of the arc suppression coils in all these substations.

After detailed analysis it was found out, that the capacity of the coils is insufficient. It would be necessary to replace current ASCs to enable standard operation and operation of special network configurations in case of some seasonal manipulations.

The installation of the combined arc suppression coil in the area of the new 35 kV network was considered as the best possible solution with regard cost and labour. It is not necessary to replace old arc suppression coils in supplying substations. The area is compensated by decentralised combined ASC in its own switching station placed on the foundation of original 35/10 kV transformer, so in case of manipulation or nonstandard situation it is guaranteed the compensations of phase-to-earth capacitance. It doesn't matter which station it is currently connected to. It is also easier for the operator, because it is not necessary to check the capacity of the compensation during the special manipulation of the network.

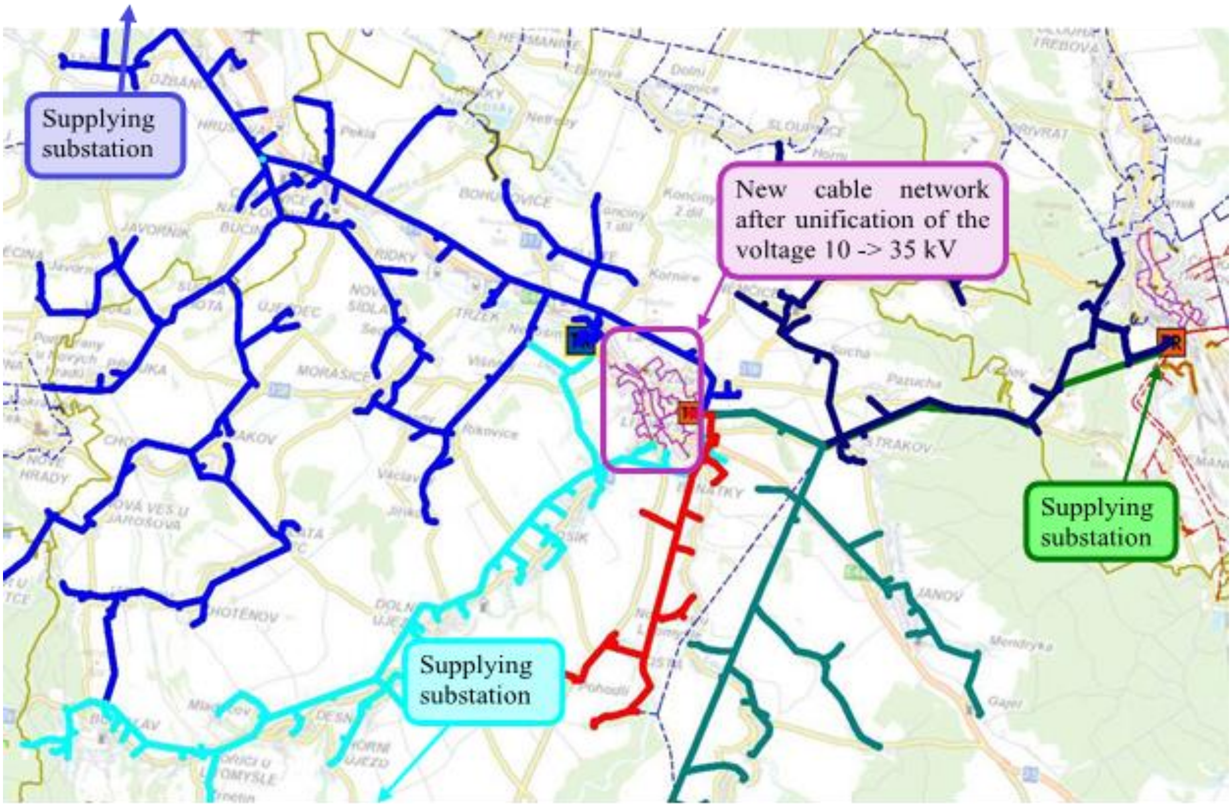

Figure 4: Situation of adding the combined arc suppresion coil.

8. CONCLUSION

Using a combined arc suppression coil for compensation of earth fault capacitive current may be very advantageous in some cases. In case of network expansion and insufficient arc suppression coil power it is not necessary to replace the original coils with new and more powerful ones. Combined coils can be installed near to the new part of the network. It also improves the network manipulation, because there will be just small steps in the whole system detuning.

Combined arc suppression coil also reduces the demands on the place, because it consists of the grounding transformer and arc suppression coil in one case. It is not needed to build two foundations, but just one.

It is also advisable to choose proper dimensioning of the combined coil to complement the arc suppression coil in the neutral point of the HV transformer and not to have too many installations in the networks.