

Electric Power System Under-Voltage Load Shedding Protection Can Become a Trap

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Abstract: Problem statement: Under-Voltage Load Shedding (UVLS) protection of Electric Power Systems (EPS) is frequently used against Voltage Collapse (VC), however when there is automatic bus voltage regulation with excessive capacitive compensation, the UVLS scheme may not trip. In this case, load shedding must be based in a Voltage Collapse Proximity Indicator (VCPI). Many UVLS procedures may not be appropriate today. **Approach:** In order to elucidate the problem stated, several studies were carried out using MatLab/SimPowerSystems. In the first case, it was simulated a reduced electric system consisting of an infinite-bus feeding a load through a large impedance line. Two other cases were simulated now including a fixed capacitive impedance (representing a saturated SVC or similar) with 25 and 60 MVar, both with a generator regulating the load bus voltage. Graphic curves representing the load bus voltage versus time were obtained with the application of a ramp power load. **Results:** In all cases the curves showed if there was sufficient time to command the UVLS scheme. The usual UVLS criteria failed for the third case. As the capacitive reactive power of the saturated compensation devices was increased, their equivalent capacitance, corresponding to the sum of maximum MVar capacities, grows. The load demand increase, after MVar saturation, can cause a voltage decrement which is too fast for UVLS adequate operation. **Conclusion/Recommendations:** Based in past experiences, any operator could be confident on existing UVLS protection of some area, but a VC can occur with the current situation without UVLS trip, as stated. It was suggested to check the current UVLS operation conditions, especially in areas where there was a growth of both load demand and reactive power resources. When UVLS method is found ineffective, then a suggestion is to replace it by a technique based upon some VCPI.

Key words: Electric power system, load shedding, SVC saturation, UVLS, voltage collapse

INTRODUCTION

There are many UVLS schemes in operation around the world, because they provide a low cost protection technique against voltage collapse. The VC of a particular area can cascade to larger areas of the electric power system. So the security of the UVLS protection against VC is very relevant in order to avoid adverse economic and social consequences.

The operation of installed UVLS can no longer give EPS protection against VC, after continuously growth of installed load demand followed by reactive power injection at system buses.

As the load demand is increased new specific devices are installed to supply the required reactive

power in order to keep the bus voltage level within standard limits.

This reactive power can be provided by shunt capacitors bank, Static VAR Compensator (SVC), Static Compensator (STATCOM) and other Flexible AC Transmission Systems (FACTS) devices.

When the demand of each reactive power source rises above its maximum capacity (with saturation), this effect can be represented by a constant impedance shunt capacitor bank. The same technique is also valid for the sum of several of these resources at a load bus.

In such situation VC may occur in a short period, since the installed UVLS scheme is no longer capable to avoid the fast voltage decrement. This phenomenon could be a trap to the operator if he was trusting in

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UVLS protection, because a too capacitive bus situation can turn it ineffective. The undesirable aspect of a very capacitive load bus was explained in the last study of the same researchers published in this journal^[1].

The UVLS scheme is based on the supposition that the VC could happen after the protected load bus voltage remained below a limit (0.92 pu for instance) for several seconds. This would occur after the reactive power support was exhausted, which would indicate the load shedding as an appropriate solution. Such alternative is useful when the bus voltage decreases slowly. In this case an adjustable-time under-voltage relay can be responsible for load shedding. The relay trip time is set between 3-10 sec^[2]. Smaller times are not used in order to avoid undesirable trip. This time range is not adequate to avoid a VC for fast transient voltage phenomena, which may occur when rapid response load components are present. The voltage stability study has recently been classified^[3] in two kinds of phenomena:

- Short-term voltage stability
- Long-term voltage stability

The UVLS scheme that is adequate to the second case can be inadequate for the first. This is illustrated in this study.

To elucidate the problem explained above, it was used a reduced electric system with a shunt capacitor at the load bus to represent the sum of the saturated reactive support devices. A generator remains regulating the load bus voltage after the mentioned reactive support of other devices. The terminal voltage upper limit adopted is 1.05 pu for this generator. When the generator reaches that limit and the load continues to grow, the decrement of the load bus voltage is so fast that UVLS has no time to trip. This is detailed in this study.

When the load bus has its voltage regulated by a synchronous generator or a similar device the reactive power injection is automatically provided as required. If the reactive power limit is reached and the UVLS do not trip, then VC will occur. In this case, in order to avoid it, a VCPI must be used to indicate the need for load shedding. As an example EPRI's^[4] implemented the "Voltage Instability Load Shedding" (VILS) device.

The VC event in a load bus is very dangerous since in can spread over a wide system area.

Besides the case exemplified above, there are situations where VC occurs even though reactive power support is still available or no low voltage problem is

detected at a bus. These situations were illustrated by the researchers in the previous study^[1].

MATERIALS AND METHODS

The load shedding at a bus was analyzed through the software MatLab/SimPowerSystem using a numerical example with the following cases:

- Without reactive power support as shown in Fig. 1
- With 25 MVAR reactive power injection, which is equivalent to a fixed shunt capacitor bank and a synchronous generator connected to the bus load through a transformer, as shown in Fig. 2
- With the same configuration of the second case, but with the capacitor bank reactive power increased to 60 MVAR

Simulated models: Figure 1 shows the example system, which consists of an infinite-bus that feeds a load bus through a large impedance line.

Figure 2 shows the model improved by the inclusion of a capacitor bank and bus voltage regulation provided by a synchronous generator connected to the load bus through a transformer.

In all cases, it was considered a high percentage of constant power type load. A certain portion of the load was supposed to be available to be switched off when needed to avoid VC. The power load growth was simulated by a ramp rate with the power factor kept constant.

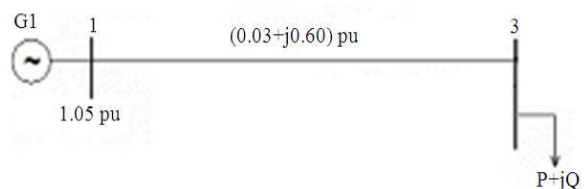


Fig. 1: One-line system diagram without reactive power support

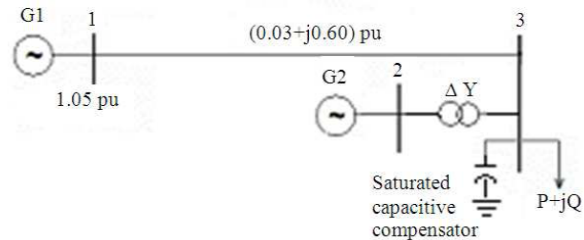


Fig. 2: Online system diagram of the improved system (with reactive power support)

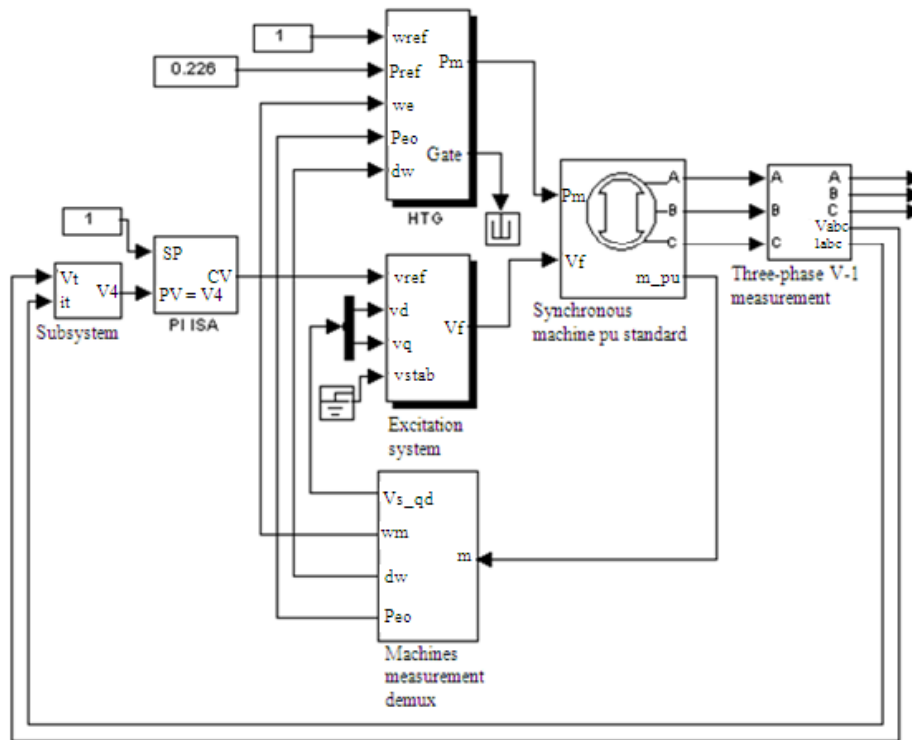


Fig. 3: Details of generator 2 regulation blocks

All per unit numerical values of Fig. 1 and 2 are referred to 138 kV, 100 MVA, as follows:

- Generation at bus 1 (infinite bus) represented by an ideal generator with 1.05 pu terminal voltage
- Generation at bus 2 (Fig. 2) represented by 13.8 kV, 200 MVA generator (with other associated parameters taken from MatLab default data bank), equipped with an Automatic Voltage Regulator (AVR) to adjust the bus 3 voltage to 0.95 pu (Fig. 3)
- Large^[1] impedance line (0.03+j0.60) pu between buses 1 and 3
- Transformer 200 MVA, 13.8 kV(Δ)/138 kV(Y), between buses 2 and 3 with equivalent impedance (0.0054+j0.016) pu
- Constant power load at bus 3 growing at 1.28 MW min⁻¹. Power rate with 0.928 inductive power factor
- A capacitor bank at bus 3

A simplified system was used in order to clearly show from a simple example that, if excessive capacitive compensation is provided, then, the VC may not be avoided anymore by means of an UVLS protection scheme.

Automatic voltage controller adjustment: It was adopted the Proportional and Integral (PI) controller to adjust the bus voltage by Ziegler-Nichols second method^[5]. The critical gain $K_{CR} = 30$ and correspondent period $P_{CR} = 0.04$ s, needed for the parameters calculation, were obtained by simulation, yielding to the proportional and integrative gains $K_p = 13.5$ and $K_I = 36$, respectively.

The controller output variable was limited to maximum value of 1.05 pu, which should be a usual limit if there was a local load bus near to the generator. Hence a generator maximum reactive power was established.

The controller feedback signal was the bus 4 voltage V_c , which is calculated^[6] from generator 2 terminal voltage V_T and current I_T , taking into account the voltage drop along the pu impedance $R_c + jX_c$ of both transformer and line. The expression used is given by Eq. 1:

$$V_c = \hat{V}_T - (R_c + jX_c) \hat{I}_T \quad (1)$$

RESULTS

Considering the application of the load power ramp rate at bus 3, several cases were simulated as described below.

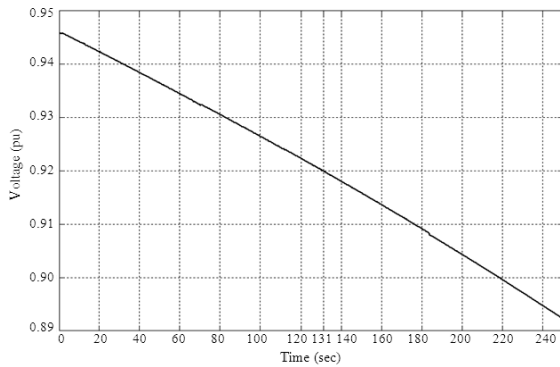


Fig. 4: Load bus voltage response without reactive power support

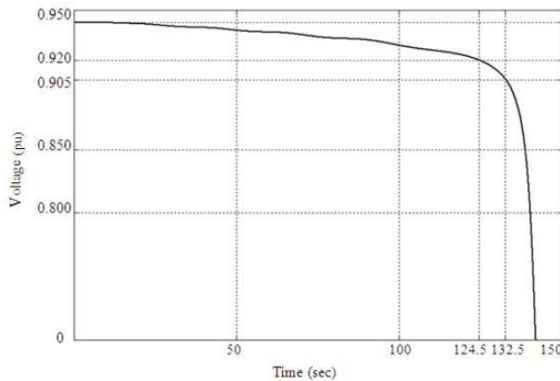


Fig. 5: Load bus voltage response with 25 MVAR capacitive shunt compensation and generator voltage regulation

The case without reactive support corresponds to Fig. 4, where the load bus voltage curve versus time was drawn focusing the voltage interval from 0.92-0.90 pu and the corresponding time interval from 131-218 sec.

Figure 5 shows the load bus voltage curve versus time, beginning with 0.95 pu. The VC phenomenon occurs with saturated reactive power sources represented by a 25 MVAR capacitor bank and the generator voltage regulation in operation till it reaches the over voltage limit.

Similarly, Fig. 6 shows the load bus voltage curve versus time, beginning with 0.95 pu and the occurrence of VC with saturated reactive power sources represented by a 60 MVAR capacitor bank. The generator voltage regulation is also kept in operation, till it reaches the over voltage limit.

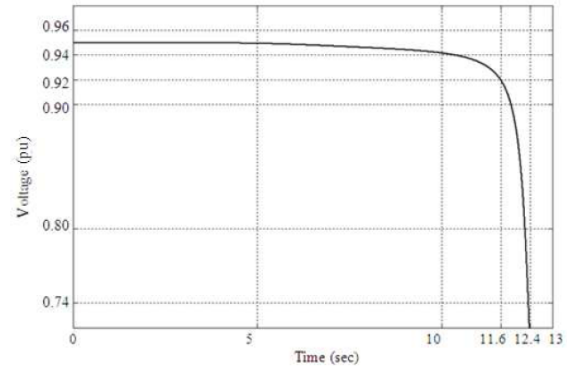


Fig. 6: Load bus voltage response with fixed 60 MVAR capacitive compensation and voltage regulated by synchronous generator

DISCUSSION

In many cases around the world it is used the UVLS scheme in order to keep the EPS bus voltages above their allowed lower limit values and, thus, avoiding the VC. The condition to start the load shedding is given by the permanence under a certain voltage limit for an adjusted time. These voltage and time limits are established for each application. This is exemplified as follows.

In Puget Sound area^[2] of WSCC it is adopted the voltage limit between 0.90 and 0.92 pu, with the allowable time adjusted to a value in the interval between 3.5-8 sec.

In Calgary area^[7], the AESO operator established, in the first stage, the trip when two or more of three monitoring stations remain below 131 kV (0.95 pu) for at least 4 sec, with UVLS of nearly 90 MW.

In the mentioned examples, as in most cases, the UVLS can no more operate, in the case of growth of both load demand and capacitive compensation resources. The VC could occur so fast that there would not have enough time for UVLS trip. The simulations of this study were performed in order to elucidate this problem.

In the first EPS case, without voltage compensation, whose one-line diagram was shown in Fig. 1, the above examples of UVLS schemes would work successfully. It can be observed from Fig. 4 that the time the voltage takes to go down from 0.92-0.90 pu is large (about 17 sec) and more than enough to avoid VC through load shedding scheme.

The second power transmission case is similar to the previous one and its configuration is represented in the one-line diagram of Fig. 2. Figure 5 shows that the same UVLS scheme would again be successful because

the delay time taken by the voltage to drop from 0.92 pu till 0.90 pu (8 sec), although not being so large as in the first case, is grand enough to turn on the load shedding in order to avoid VC.

For the third case, it was supposed that, after a number of years, the economic progress of that system area would require new reactive power shunt devices to cope with load demand increase. Therefore, it was analyzed a situation where the old and new reactive power devices were fully used, supplying their maximum reactive power that was equivalent to a fixed capacitive reactance of 60 MVAR. Starting from this situation, with load bus voltage regulation provided by the generator, with 0.95 pu initial value, it was shown in Fig. 6 that the load growth causes a voltage drop so sharp that the UVLS scheme would not be able to trip.

In Fig. 6 it was observed a delay time of less than 1 sec for the voltage to fall from 0.92 pu to the VC point. Therefore, the VC only occurs because there would not be sufficient time to initiate the load shedding. Cases such as those at Puget Sound area, Calgary area and many others UVLS schemes would not be effective after their load buses become too much capacitive.

CONCLUSION

The operator that lived experiences of UVLS successful protection in the past time, like cases 1 and 2 described above could be confident of the existing protection against VC. But if both the reactive power resources and the installed power load demand are now bigger than in the past, then the operator could be in a trap. This is because the new electric power grid parameters do not permit the UVLS operation which could end up in a VC. This is shown in the third simulated case.

It is suggested to check the operational condition of the existent UVLS schemes, especially those related to buses in areas where there were increase in both load demand and reactive power resources. It can be found that many of those UVLS schemes do not adequately protect the power system. The VC could happen now so fast that these UVLS schemes would have no time to trip the load.

The devices that are now inadequate, because of the mentioned conditions, must be replaced by VILS^[4] or similar devices that perform load shedding based in loadability margin or other VCPI limit.

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