Automatic Voltage Control of Networks with Embedded Generation

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1. Introduction

This paper discusses the application of transformer automatic voltage control (AVC) to networks in which generation is embedded, with reference to the application of MicroTAPP voltage control to these systems.

The issues addressed here are the particular problems that can occur if the application of voltage control does not take into account the presence of generation. It addresses any requirements on a local (i.e. distributed) level. An overall network solution may make use of a network automation system to set up the voltage control relay (VCR) for the system conditions. This, however, is a network management issue and is not relevant to the voltage control application.

1.1. Voltage Control Basics

In order to set the scene, some of the issues to be addressed when controlling the voltage on networks with embedded generation are discussed here, beginning with a recap of basic voltage control theory.

The simplest form of AVC can be used where a single transformer supplies a single load (Figure 1). If the load is some distance from the transformer, there may be a voltage drop in the line. The AVC relay measures the voltage and the current (V_{VT} and I_{CT}) and makes an estimate of the voltage at the load (V_{eff}) using a model of the line ($R_{line} + \mathrm{j}.X_{line}$).

The above represents the ideal situation: in reality there are usually a number of loads on a transformer distributed at different distances (electrically) from the transformer, so the model of the line will always be a compromise. The model is normally set up to establish a constant voltage point at the mid-point of the network, thus achieving a minimum overall variation between the no-load and full-load conditions.

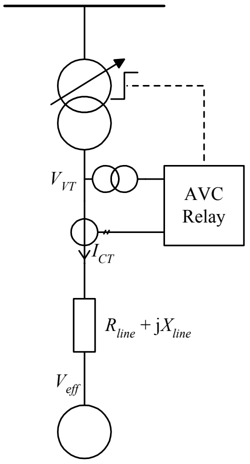

Figure 1 Transformer connected to single load

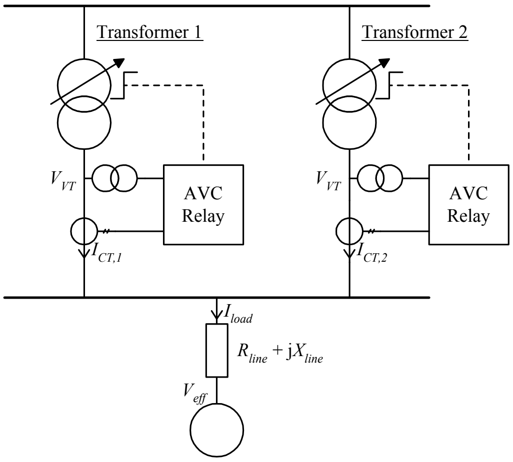

Figure 2 Parallel transformers connected to single load

It is common practice to parallel transformers in order to give a higher security of supply (Figure 2). For a site with two transformers in parallel, the load on each transformer is half of the total load. In order to obtain the correct voltage boost it is necessary to summate the loads of all paralleled transformers ($I_{load} = I_{CT,1} + I_{CT,2}$).

If the open circuit terminal voltages of the paralleled transformers are not identical, a circulating current will flow around them. This will be highly reactive since the transformers are highly inductive. If two paralleled transformers operate the simple AVC scheme described above, eventually one transformer will be on the highest tap and the other on the lowest tap. The busbar voltage will be an average of their terminal voltages and a high amount of circulating current will flow between them. This will cause an unnecessary power loss within the transformers and the network, reducing their useful capacity and their efficiency.

Therefore, the main aims of any voltage control scheme must be to:

1. maintain the correct voltage at the customer, taking into account line voltage drops, and,
2. minimise reactive circulating current around paralleled transformers, and across networks.

1.2. Application of MicroTAPP

The MicroTAPP scheme, based on the negative-reactance AVC scheme, resolves the measured current of each transformer into load and circulating elements. Figure 3 shows the current seen by an AVC relay ($I_{CT,1}$) with respect to its phase voltage (V_{VT}). The circulating current (I_{circ}) is resolved from $I_{CT,1}$, being the deviation from a set-point of system power factor (pf_{sys}). This element of current is then used to bias the voltage control in order to minimise the circulating current.

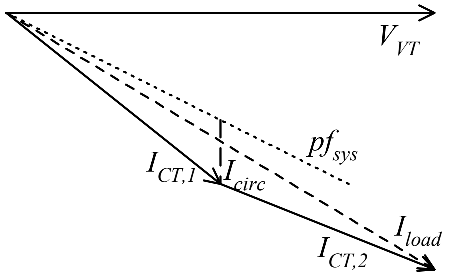

Figure 3 TAPP Scheme

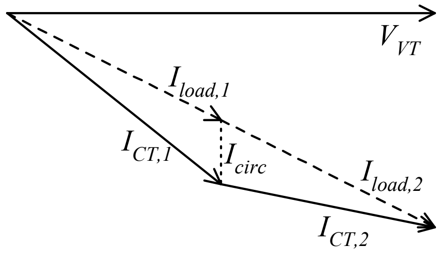

Figure 4 True Circulating Current Scheme

Line drop compensation (LDC) corrects for system voltage drops in order that customers receive as close to ideal voltage as is possible. The total load on the busbar is calculated by summating transformer currents $I_{CT,1}$ and $I_{CT,2}$ (Figure 3) and this is used to calculate a bias to apply to the voltage control.

These two simple elements together achieve the main aims of voltage control. Other benefits of this system are that:

- the system is extremely simple,
- transformers and tap-changers on a site do not have to be identical,
- the incoming voltages can be different, and,
- transformers can be paralleled across networks.

Although the actual power factor at a particular time may not be the specified power factor pf_{sys}, as long as the deviation is not large the voltage control will be satisfactory. If the actual power factor varies greatly from the set-point, the effect will be an error in the controlled voltage, due to load current being considered as circulating current by the TAPP scheme.

1.3. Varying Power Factors

In circumstances where the load power factor can vary substantially, the TAPP scheme with its power factor set point may not be a viable option. An alternative scheme, known as the true circulating current scheme, is described below and can be used in these circumstances.

Figure 4 shows the current seen by two AVC relays $I_{CT,1}$ and $I_{CT,2}$, with respect to their phase voltages V_{VT} (when the transformer LV circuit breakers are closed the measured voltages will be identical). The load currents, $I_{load,1}$ and $I_{load,2}$, have the same power factor. Transformer 1 is on a higher tap position than transformer 2, hence a circulating current will flow represented by I_{circ} in the diagram. If the measured currents, $I_{CT,1}$ and $I_{CT,2}$, are summated, the network power factor can be found. The true load on each transformer and its contribution to circulating current can be established. Therefore LDC error is eliminated.

2. Embedded Generation

For the following discussion, an example network is used, shown in Figure 5.

For the purpose of explanation a single transformer is shown supplying load to a nominal 33kV busbar and the load is assumed to be unity power factor. Three circuits are supplied from the busbar. Load C is interconnected to a remote substation and so for operational flexibility, the voltage control to the transformer tap changer is configured for reactive control (TAPP). If Load C is not interconnected to another site, true circulating current control can be implemented.

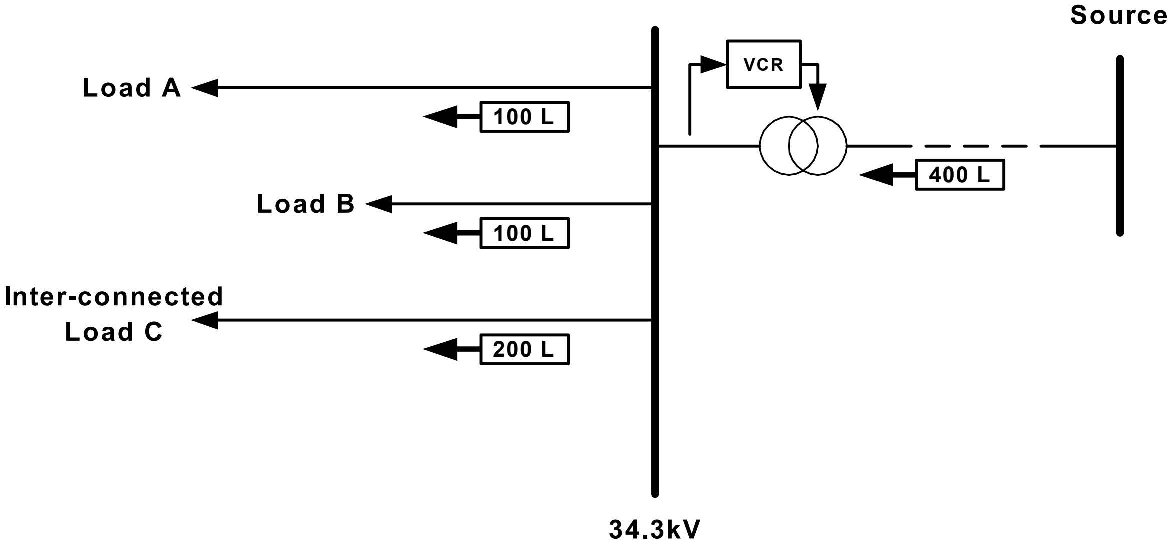

Figure 5 Example Network for Embedded Generation Scenarios

The basic voltage level setting is set to 33kV and at the transformer load shown (400L) the load drop compensation (LDC) applied at 4% increases the busbar voltage to about 34.3kV. These figures are used for the purpose of explanation only.

A number of scenarios involving generation embedded in this network are now discussed.

2.1. Small Asynchronous generator

Small generators can be embedded remote from the busbar and supply part or the entire feeder load. It is unlikely that a generator in this location would be capable of supplying the total substation load. Figure 6 shows a generator connected to supply the feeder load. The generator reactive load is supplied from the source through the transformer (50R), with the result that the transformer contributes a smaller load to the busbar, at a lower power factor due to the increase in reactive current.

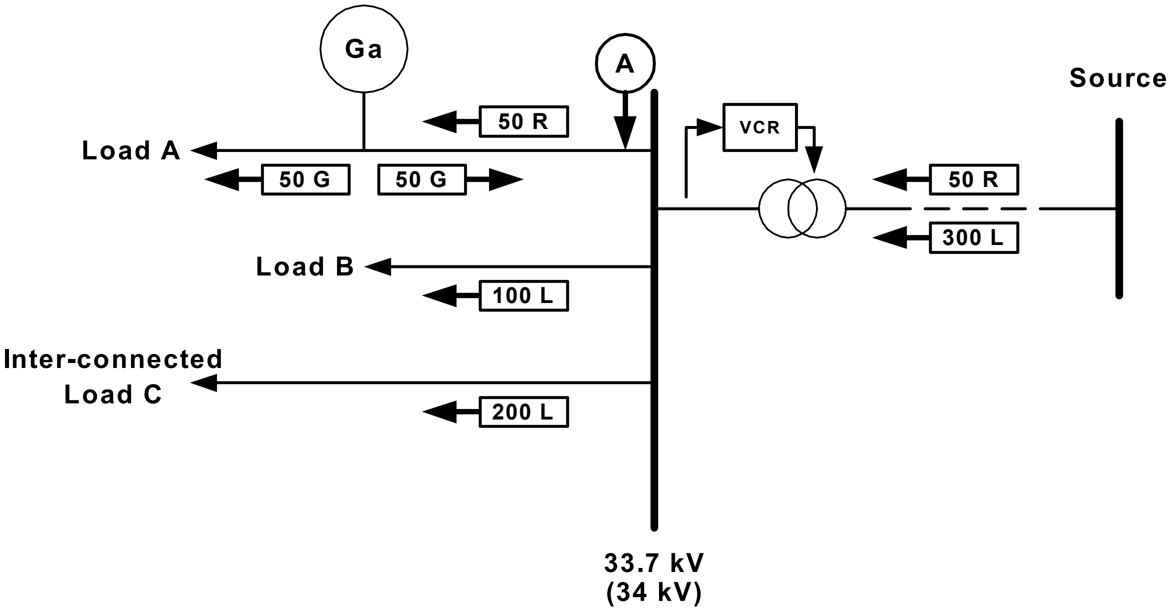

Figure 6 Remote Embedded Asynchronous Generation

As the real load has reduced, the LDC effect is reduced causing the LDC boost voltage effect to be reduced to 3%. As the voltage control is in TAPP mode the decrease of power factor causes an error in the VCR target voltage that results in a further 1% reduction in voltage.

When the generator is running then the busbar voltage is reduced to 33.7kV from the desired 34.3kV.

Solution

If the generator contributes an insignificant load relative to the transformer, the effect on the VCR will not be significant. If the generator causes a significant change to both the transformer load and power factor, steps can be taken to exclude feeder load A from the transformer current applied to the VCR CT input. The transformer load will now ignore the effect of all generation connected along feeder A.

This can be achieved by use of a “load exclusion module” (LEM) applied at point A. This module subtracts load A from the current measured by the VCR CT. The current seen by the VCR will now be of the correct power factor and the LDC effect will be slightly reduced to 34kV (since it does not include load A). This can be corrected by a small increase to the LDC setting.

2.2. Large Asynchronous Generator

Large generating capacity would most likely be connected at the busbar and be able to supply a high proportion of the site load. Figure 7 shows a generator connected at the busbar. The generator reactive load will be supplied from the transformer, the result being that the transformer contributes only reactive current to the busbar. In this case the power factor of the transformer load will swing towards 0pf lagging and, depending on the magnitude of the reactive current, have a significant effect on the VCR target voltage.

The real load is now reduced further, the LDC effect now being 1% instead of 4%. The large reduction in the apparent power factor also results in a target voltage error, say a further 2%.

The sum of these effects is that, when the generator is running, the busbar voltage is reduced to 32.7kV from the desired 34.3kV.

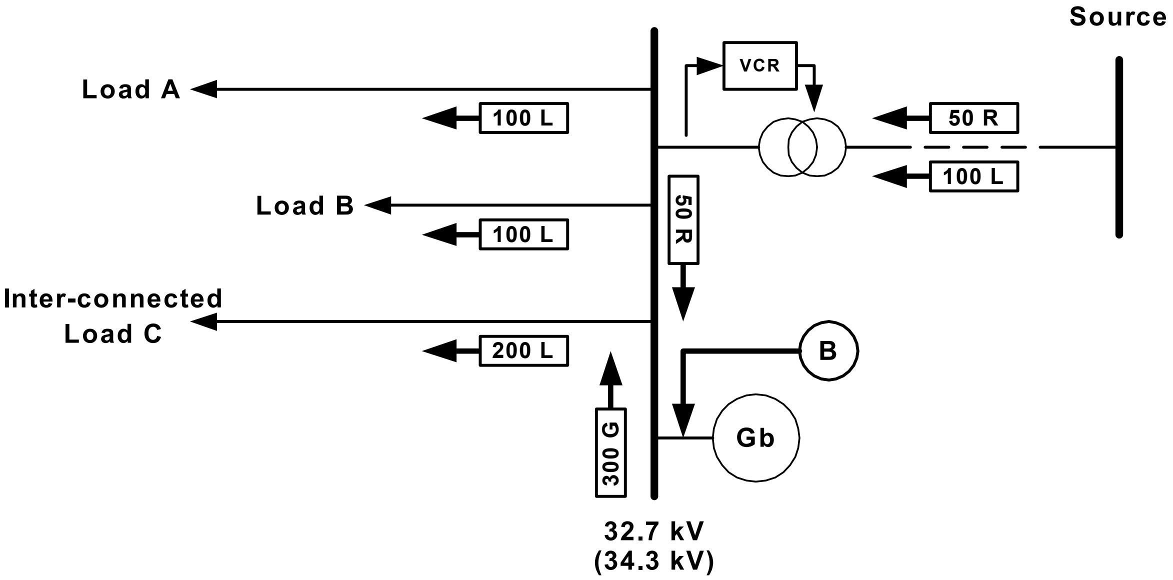

Figure 7 Large Embedded Asynchronous Generation

Solution

The generator will cause a significant change to both the transformer load and power factor. If the generator current is excluded from the VCR CT input the transformer VCR will ignore the effect of the generation and assume the load connected only to the outgoing feeders. The VCR will, therefore, remain accurate at all times (34.3kV).

Again, this can be achieved by use of the load exclusion module, applied at point B.

2.3. Synchronous Generator

Figure 8 shows a generator connected to the busbar. The generator is set to produce power at the system power factor and the transformer VCR will control the busbar voltage level.

The generator in this case is supplying virtually the complete busbar load, leaving the transformer at no load. As the transformer is at no load the LDC effect is zero and the voltage reduces to the basic set point level of 33kV.

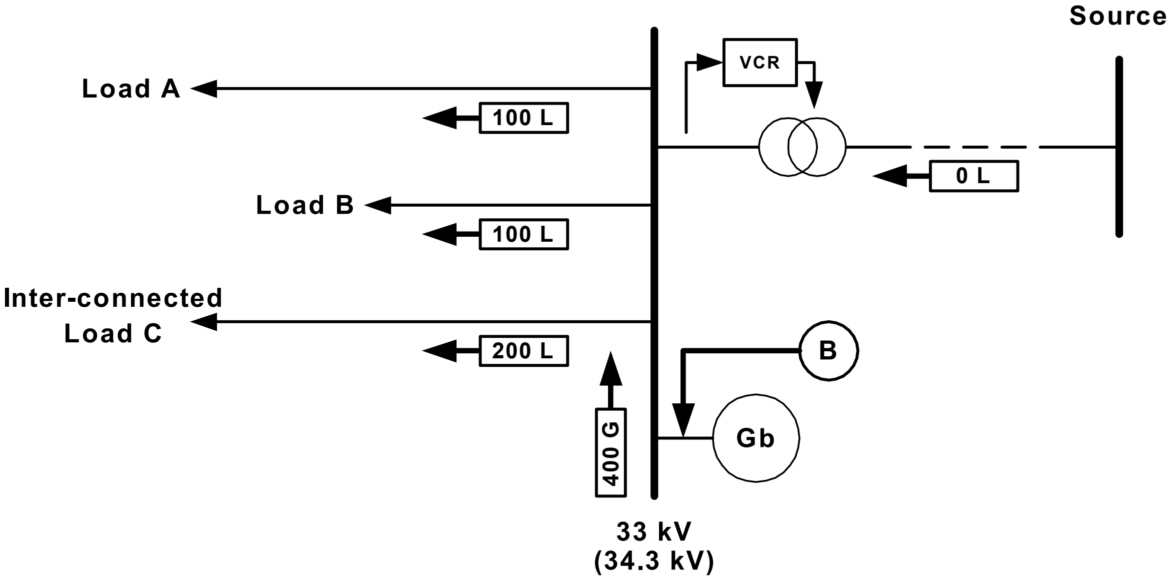

Figure 8 Synchronous Generation

Solution

The generator will cause a significant change to the transformer load. If the generator current is excluded from the VCR CT input the transformer VCR will ignore the effect of the generation and assume the load connected only to the outgoing feeders. The VCR will, therefore, remain accurate at all times (34.3kV). If the overall supply source is strong (high fault level) in relation to the local busbar, this solution will allow energy to be supplied into the higher voltage network.

This can be achieved by use of the load exclusion module, applied at point B.

2.4. Large Synchronous Generator

Figure 9 shows a generator connected at the busbar and power being exported into the higher voltage network. If the generator is set to produce power at the system power factor and the transformer VCR set to control the busbar voltage level, the system voltage may be in serious error.

The sense of LDC will be in reverse and a corrective action by the VCR will increase the primary/secondary winding ratio, thus making the secondary voltage reduce to a point where the voltage is below the basic voltage level by an amount equivalent to the LDC setting value, in this case to 32.3kV.

In this situation, LDC cannot be used, which is operationally restrictive. If the primary system has a relatively low fault level the transformer voltage control may have to be disabled completely.

Solution

The generator will cause a significant change to the transformer load. If the generator current is excluded from the VCR CT input the transformer VCR will ignore the effect of the generation and assume the load connected only to the outgoing feeders.

If the overall supply source is weak (low fault level) in relation to the local busbar it may be required to transfer voltage control to the higher voltage network when the generation in running and allow the voltage of the local busbar to be controlled by the generator.

The MicroTAPP voltage control system can be configured in this situation to operate in ‘pseudo VT’ mode. Under this operating condition, the existing LV VT and CT are used, and the voltage at the transformer HV terminals is calculated. The MicroTAPP then operates the tap changer to maintain the “incoming” voltage at the correct level.

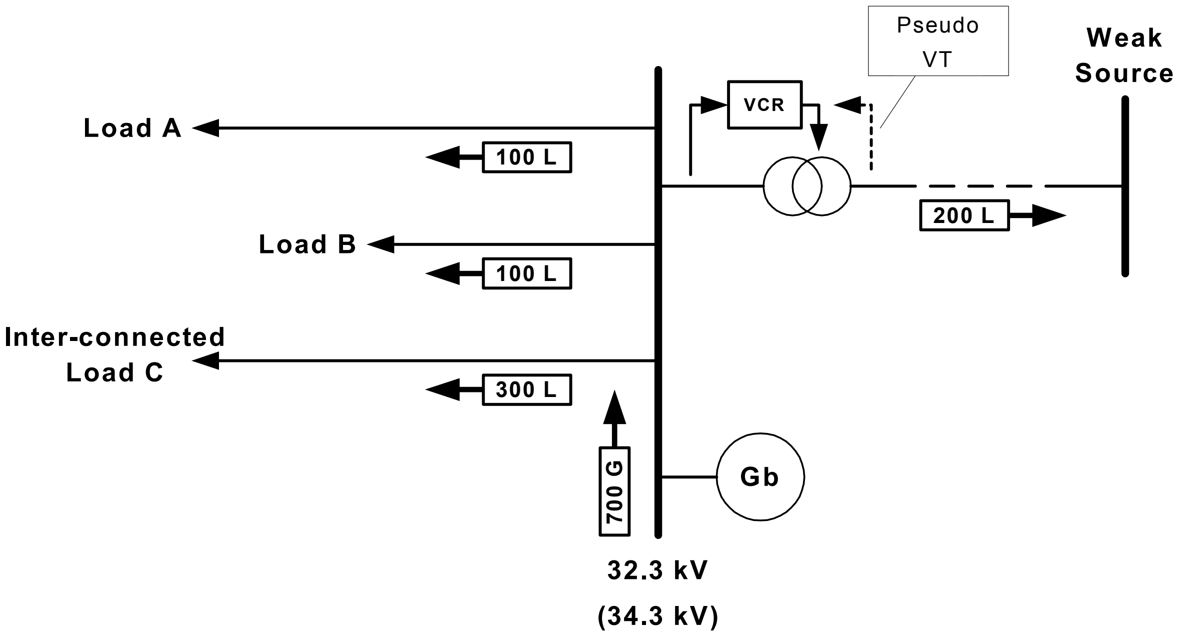

Figure 9 Large Synchronous Generation

3. Summary

Generation type		Asynchronous Generation		Synchronous Generation		
Size (relative to network strength)		Small	Large	Small	Large	
					Pf control	Voltage control
Expected location		Embedded remote from busbar	Busbar	Busbar	Busbar	Busbar
Voltage Control	At point of generation	Generator	Transformer AVC	Transformer AVC	Transformer AVC	Generator
	Of busbar	Transformer AVC				
	Of HV network	by System	by System	by System	by System	Transformer AVC
Special requirements		None	Use LEM	Use LEM	Use LEM	Pseudo-VT mode