SUPERTAPP

Contents

1. INTRODUCTION

The comprehensive design of the RVM series of relays and the TAPP circuitry simplifies the design of a tap change control system. In order to provide a complete understanding of the benefits and application this guide includes the use of the RTMU monitor relay and RTPI tap position indicator when describing the various applications.

2. NETWORK REQUIREMENTS

An important aspect of supply quality is the correct application of voltage levels to all transmission and distribution networks. With a growing amount of embedded generation, both synchronous and asynchronous types are now becoming relatively common within distribution systems. The control of voltage levels require control systems which can function under dynamic operating regimes. This need, coupled with growing customer expectation and use of sophisticated electrical equipment such as computers and thyristor controlled machinery puts an added responsibility upon the supplier of electrical energy to ensure that the delivered level and quality of supply is always within the parameters set down by regulatory bodies.

Automatic voltage control of the electrical network is implemented by use of voltage sensing relays which control motorised On Load Tap Changers (OLTC), for distribution system these devices are normally not economic below a transformer secondary voltage of 11kV or 6.6kV. The complexity of these systems and the mechanical nature of the OLTC contribute to the long term unreliability and danger of abnormal voltages being applied to the distribution system. The main problem areas with traditional schemes are:

- Complex control circuitry associated with the parallel operation of transformers in a substation
- Operational limitations when networks are operated in parallel
- Inadequate performance under varying load conditions
- High skill requirement for installation, operation and maintenance

The SuperTAPP system when applied in a practical manner can overcome these historical problems associated with voltage control.

2.1. Voltage Standards

The allowable range of permissible voltage at each customer's supply point determines to a large extent, the operational voltages that can be applied at each voltage level on the network. Using typical voltage ranges it will be useful here to examine the maximum typical design voltage drops that can occur across a distribution system at extreme loading conditions.

For this example the network voltage levels are: 33kV, 11kV and LV.

Table 1 lists voltage drops starting at the in-feed point, this example being only one of many, but used here for the purpose of explanation. The tables use figures for fixed tap distribution transformers based on a nominal output equivalent to the statutory voltage and off load adjustment in ±2.5% and ±5% steps. In practice the nominal voltage of fixed tap transformers is higher than the statutory voltage, giving a fixed boost over the levels used in this example.

Under the conditions shown in Table 1 where a basic control of voltage is used to give a constant voltage at the 11kV busbar, a customer connected close to the 33/11kV source can receive a supply that varies by only 1.5%, while a customer connected at a remote point on that network can receive a supply having a variation of some 16.5%.

Improved system utilisation can only be achieved and adequate voltage levels maintained if compensation for the full load drop can be successfully applied to the voltage control system such that variations at the load end can be minimised.

Table 1 - % Voltage Difference (from nominal)	At Source		Remote End	
	No Load	Full Load	No Load	Full Load
33kV System and Transformer	0	-7	0	-7
33 / 11kV Transformer (Basic 100% used to offset 33kV system drop)	0	+7	0	+7
11kV System	0	0	0	-8
11kV / LV Transformer	0	-1.5	0	-1.5
LV System	0	0	0	-7.0
Total	0	-1.5	0	-16.5

No Load/Full Load Variation	1.5	16.5

2.2. Increasing the Network Capability

A method of Automatic Voltage Control (AVC) with Line Drop Compensation (LDC) has been used to offset the effects of line drops due to the load current effect upon the line R/X characteristic in order to achieve a constant voltage at the far end of a transmission line. This method is not practical for distribution systems where customers are connected along the length of multiple feeders radiating from a single substation with each feeder having a different load characteristic. The theoretical calculation of usable settings is, therefore, difficult for a distribution network.

If use of LDC is considered as LOAD Drop Compensation it can be employed in a practical way to increase the network utilisation. Using the data from Table 1, a modified basic level setting of -2.5%, and an LDC setting of 5% is applied to the AVC. The effect on the voltage levels at the extremes of substation loading is seen by reference to Table 2.

The maximum variation across the network is now reduced from 16.5% to 11.5% through the change to the BASIC and LDC controls, resulting in an improved overall supply to the connected customers or, if the original deviation was acceptable, allowing the feeder lengths to be extended and the maximum variation indicated in table 1 still achieved.

More aggressive use of LDC will improve the situation to the ideal point where the deviation is equal at both the source and remote ends of all feeders. This situation is, however, difficult to achieve in practice.

It can be seen from this example that voltage levels at the customer supply points can be improved by the use of LDC.

While abnormal network running and disparate feeder load profiles may cause the use of LDC to be slightly limited, advantage can still be gained by the use of restricted settings, including those networks where voltage drops occur only on the LV system.

Table 2 - % Voltage Difference (from nominal)	At Source		Remote End	
	No Load	Full Load	No Load	Full Load
33kV System and Transformer	0	-7	0	-7
33 / 11kV Transformer (Basic 97.5%)	-2.5	+4.5	-2.5	+4.5
33 / 11kV Transformer (LDC 5%)	0	5	0	+5
11kV System	0	0	0	-8
11kV / LV Transformer	0	-1.5	0	-1.5
LV System	0	0	0	-7
Total	-2.5	1	-2.5	-14

No Load/Full Load Variation	3.5	11.5

2.3. A Flexible Distribution System

2.3.1. Dissimilar Transformers

For security purposes, multiple transformers are installed at distribution substations. Where OLTC's are used for voltage control, circulating currents will flow between transformers if the on load terminal voltages are not maintained to the same level at all times. For this reason it is normal practice for transformers in service at a location to have the same rating, the same number of tapping positions, tap interval and the same tap change control system. If these requirements are met it is usual for a single AVC relay to operate all tap changers simultaneously to the same tap position.

Consider, however, Figure 1. If source points A & B output different voltages and, say, the supply lines or transformers have differing impedance, a circulating current will result if the transformers are forced to remain on the same tap position and share a common busbar, C. Taking typical values for this arrangement, shown in Table 3, and considering the transformers only, approximately 26.5 amps of reactive current will circulate through the high voltage network between the two source points. Given an average loading on each line of, say 30% of transformer capacity, the effect of this circulating current will be to increase the copper losses by 11.4%.

The modified negative reactance principle used in the SuperTAPP voltage control system (detailed in the section 'description of operation') minimises any circulating current flows and, therefore, avoids this situation.

Source Voltage A	32.6kV
Source Voltage B	33.4kV
Transformer Rating A & B	10MVA
Transformer Impedance A & B	8%

Table 3

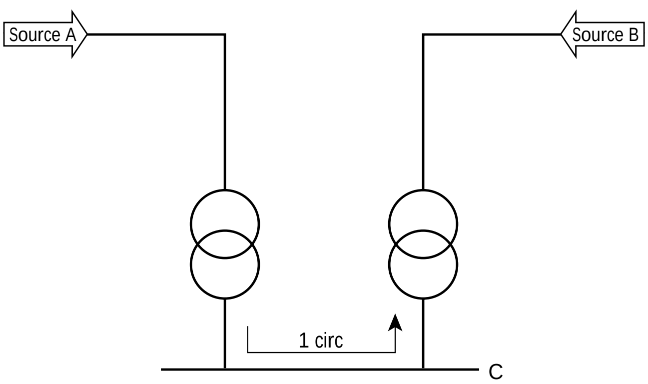


Figure 1

2.3.2. ABNORMAL FEEDING ARRANGEMENTS

When LDC is used and distribution networks are operated abnormally under high load conditions, for instance to support a remote substation during fault repairs or maintenance, voltage levels can be driven above the normal high levels. While a wider tolerance of voltage deviation may be acceptable, a danger of high voltage exists if due attention is not given to the operational settings of the voltage control system under these conditions.

The RTMU monitor relay helps to prevent abnormal distribution voltages. As the voltage monitor is set to prevent tap change operations that will increase the system voltage above a pre-set level, increases of load will not result in a corresponding increase in source voltage. The concept employed for control of the OLTC can be appreciated by reference to Figure 2.

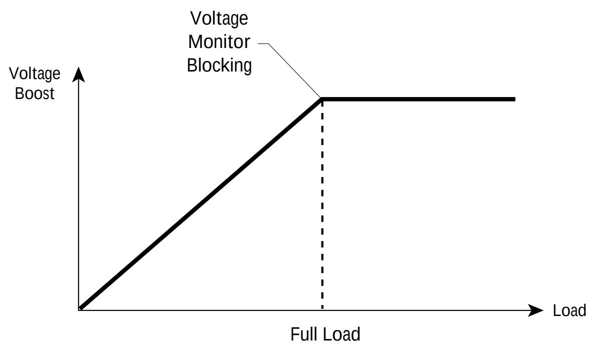


Figure 2

3. SELECTION OF RELAYS

3.1. Existing Installations

The RVM/4 relay has been designed specifically as a replacement for the majority of AVE type mechanical voltage control relays. Installation is by direct replacement, in this instance the use of the RTPI/2m tap position indicator will provide for runaway prevention.

3.2. New Installations

The RVM/5 and RTMU monitor relay has been designed to simplify the application of voltage for new or totally refurbished installations. When used external wiring is reduced to an absolute minimum.

4. WIRING DIAGRAMS

The external wiring requirement is relatively simple given the comprehensive internal design of the SuperTAPP system. Examples of a typical arrangement for control of a tap changing transformer are attached at the end of this section.

5. TRANSFORMER GROUPS

Reference to the Description of Operation section of this document explains that the use of inter-connecting bus-wires between relays at a site is for summation of load current purposes. The minimisation of circulating current is carried out by each relay using that transformer's own current. When transformers are grouped consideration must be given to the Load Drop Compensation (LDC) requirements and effects of different running arrangements.

SuperTAPP is ideally suited to double bus-bar substations allowing flexibility in the system running arrangements. The transformers do not have to be identical and can be supplied from different sources. There are three main methods of applying SuperTAPP, each with particular advantages over the others, giving the customer a wide choice depending on his particular requirements.

5.1. Independent Single Transformers

The simplest method of voltage control is to not use any bus-wires at all, Figure 3. Each transformer at a site is allowed to operate independently of others. Any circulating current between transformers connected in parallel on the same bus-bar will bias the SuperTAPP relays to operate in a direction which will reduce the circulating current to a minimum.

The effective LDC for this method is related to the load on each transformer, rather than to the connected load when inter-relay summation bus-wiring is used. In this case the effect of switching a transformer out of service will not be significant e.g. an increase in effective LDC by the ratio of the number of transformers to the number of transformers - 1. As the summation buswires are designed for use with up to 4 transformers in parallel, the single transformer method of connection can also be used when more than 4 transformers are connected together.

The method has two other advantages. The CT's for each transformer do not have to be in the same phase and other manufacturers relays can be incorporated into the overall scheme provided they can be configured for Reverse Reactance mode.

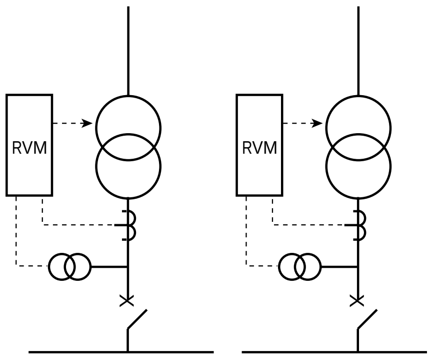


Figure 3 Single Transformers

5.2. Parallel Transformers

When transformers are operated in parallel use of the summation bus-wires provides for accurate LDC at all times. Figure 4 shows the general bus-wire arrangement for a two transformer site. In this case the summation bus-wire passes the effective busbar connected load to each relay regardless of the running arrangement.

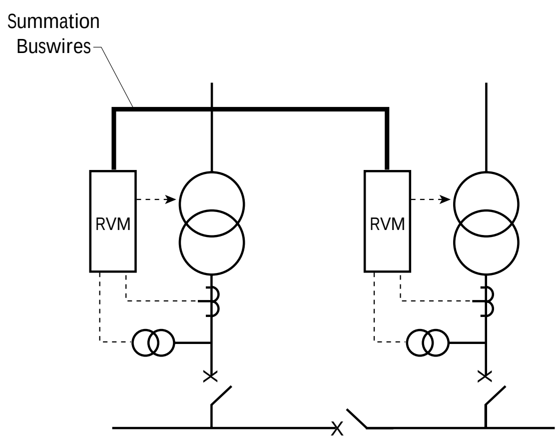


Figure 4 Parallel Transformers

5.3. Parallel Transformer Groups

In more complex sites transformers may operate in groups, where the configuration is for a single group, Figure 5, or, as in Figure 6 where the busbars are split, making two effective load groupings.

5.3.1. Single Bus-Wire Group Method

In this case all transformers at the site are connected to a single set of bus-wires. Different Basic and LDC settings can, if required, be applied to each group as in the previous method. The actual level of LDC in each case however will be always be proportional to the total substation load and therefore will suffer some (normally small) inaccuracy if the two bus-bars have significantly different load patterns.

This method has the advantage that the effective LDC value is maintained when any of the transformers is switched out of service. Furthermore if different basic settings and/or different LDC settings have been applied to the different groups then the correct compromise values will automatically be produced (based on the average) when the bus-bars are paralleled or the transformers are re-grouped.

This is probably the best all round scheme allowing both the proper use of LDC and 100% flexibility in the system running arrangement with very little compromise. SuperTAPP is unique in providing this level of flexibility and simplicity with such a small compromise in performance.

5.3.2. Multi Bus-Wire Group Method

Take an example of four transformers normally operating in, say, two groups. i.e. 2 on each bus-bar, figure 6.

If each group is provided with it's own independent set of bus-wires then different basic levels and different LDC values may be applied to each group. This can be thought of as two separate substations albeit at the same site. The actual level of LDC for each of the two bus-bar groups will be proportional to the load on each of the respective bus-bars and these levels will be maintained at the correct level even if one transformer is taken out of service in either of the groups. If the two groups are then interconnected either by closing the bus-coupler or operating the transformers in different system groups then the resulting levels of basic voltage and LDC will be a compromise based on the average settings and loading of each transformer in the new group.

This method is probably the best choice if the transformers are to be operated in clearly defined groupings for long periods and in different groupings for short temporary periods only.

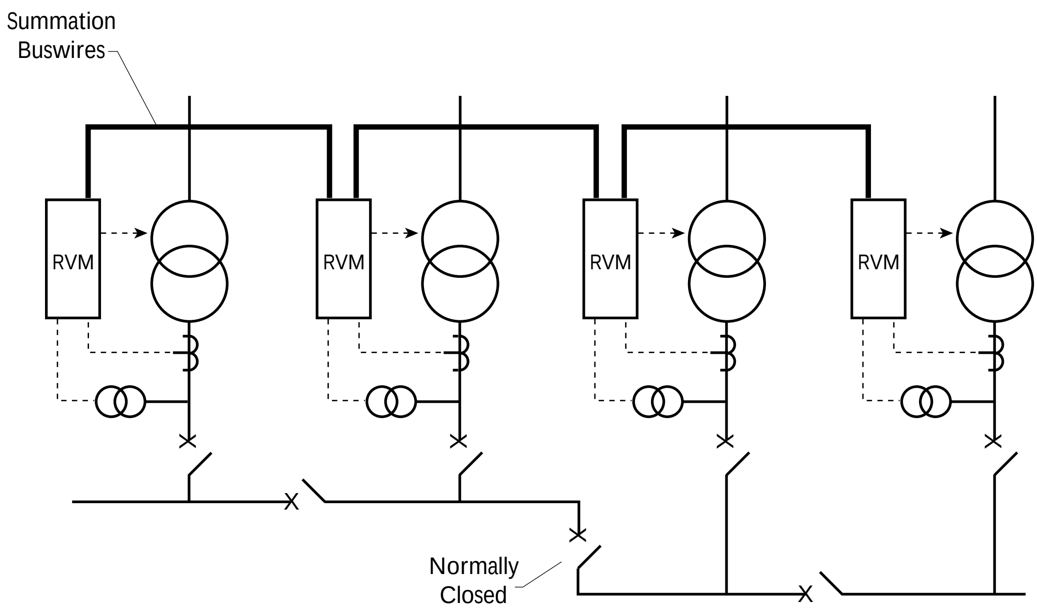


Figure 5 Transformers - Single Group

5.3.3

The above examples are achieved without the use of OCB auxiliary switches or auxiliary relays. There is another method that could be considered by automatically re-configuring the bus-wires as the system operating conditions change by using auxiliary switches in the various OCB's. This method could be become very complex and it is not good engineering practice for CT circuits to be switched. Any gain in performance would probably be very small and is not recommended.

5.4. Parallel networks

The SuperTAPP system uses a modified negative reactance design for the detection of circulating current. The inter-relay bus-wiring is used for the summation of site load current only. As the relays minimise circulating current between transformers at the same site, the same effect will be seen when transformers are operated in parallel across networks.

6. EMBEDDED GENERATION

6.1. Generator Types

6.1.1. Synchronous

It is normally possible for the generator operator to control the power factor (by controlling the field current). If the generator can be made to automatically run at a constant power factor, say between 0.9 and unity or better still at the normal system power factor of 0.96/0.97 then the effect will be to artificially reduce (or even reverse) the load on the substation.

6.1.2. Asynchronous (Induction Generators)

Induction generators draw reactive magnetising current from the power factor load current. As the SuperTAPP relay is based on the negative reactance principle for tap change control, a significant variation in load power factor may affect relay performance.

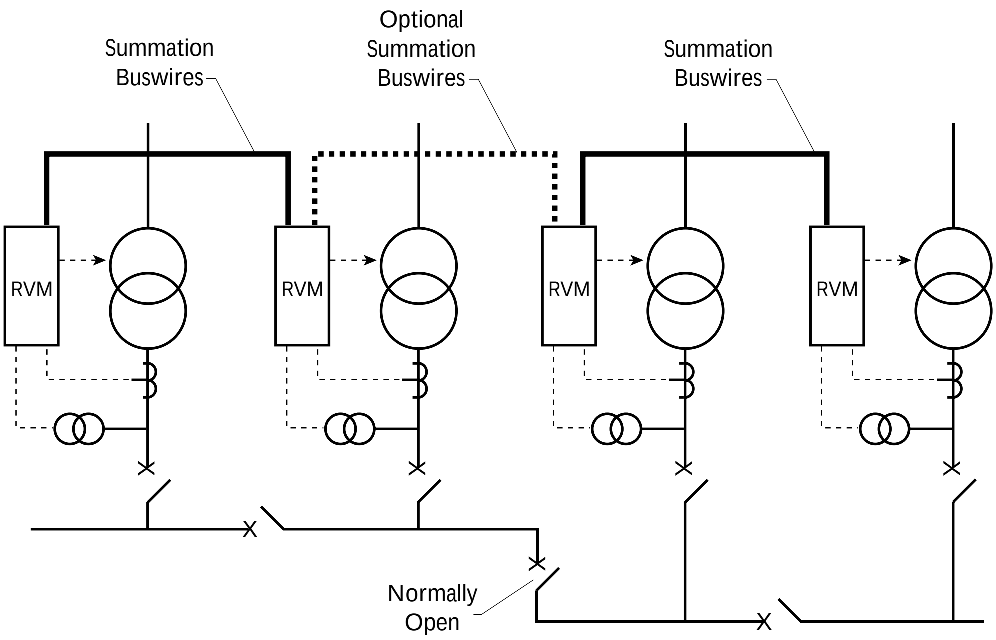


Figure 6 Transformers - Two Groups

6.2. Relative Fault Levels

Unsatisfactory results may be produced if the fault level of the public supply network is low compared with the fault level of the generator(s). Under these circumstances the transformer can be switched to manual with the voltage control being provided by the generator(s).

6.3. Application of SuperTAPP

Generally SuperTAPP can be applied as follows :

- If the generator is synchronous and the power factor can be maintained automatically within the range, say, 0.9 to unity and LDC is not a problem then no special precautions are normally necessary.

- If the generator is synchronous and has it's own OCB with a CT of suitable size then the LDC can be made proportional to true substation load by subtracting the generator current from the summation bus-wire.

If the above solutions are unsuitable then a special version of SuperTAPP can be supplied which operates using the Circulating Current principle. This makes it immune to external reactive currents. This method, in common with all circulating current based schemes, has two disadvantages. Remote substations cannot be paralleled without sterilising the automatic voltage control and OCB auxiliary switches, additional control switches & links etc. are required.

7. SYSTEM POWER FACTOR

The three classic methods of controlling transformers in parallel are Master/Follower, Circulating Current and Negative (or Reverse) Reactance. There are four main reasons why SuperTAPP is based on a modified Negative Reactance principle.

- The well known disadvantages, reliability problems and operational limitations of conventional Master/Follower systems are avoided.

- Unlike conventional Circulating Current schemes no circuit breaker auxiliary and racking switches are required to reconfigure the CT circuits when a transformer is taken out of service.

- A Negative Reactance based scheme is the only method that safely allows substations to be paralleled either temporarily or permanently through an interconnecting network without sterilising the AVC.

- Negative Reactance based schemes are inherently simple and stable.

The well known disadvantage of normal Negative Reactance schemes is the drooping characteristic of the LDC effect with increasing load at all lagging power factors. Conventional 90° Negative Reactance schemes have their best accuracy at Unity power factor. The accuracy curve follows roughly the same shape as a sine curve and at normal system power factors around 0.96/0.97 (15°) lagging, therefore, the error starts to be significant.

The SuperTAPP system employs a 30° modified Reverse Reactance principle that is optimised for minimum error at 0.96/0.97 lagging power factor. The accuracy curve is virtually flat at this point and therefore any errors due to different power factors remain quite small over a much wider normal working range before reaching the steeper parts of the curve.

It is accepted that if SuperTAPP relays are called on to operate at heavily lagging or leading power factors a reduction in LDC performance will result. There are several reasons why this does not present a problem in practice.

System power factors are almost invariably within the range of 0.9 to 0.99 lagging and rarely lower than, say, 0.75 lagging (41°) or more than slightly leading. At the extremities of this range any errors, which will still be relatively small, can easily be corrected. There are two ways of achieving this:

- The Coupling Control, which is normally set to match the transformer impedance, can be reduced to a much lower value. This will reduce any error in direct proportion to the reduction in the coupling setting but with no significant loss of the actual coupling effect.
- The LDC control can either be set higher than normal to correct a drooping characteristic, or it can be set lower than normal (or at zero) to reduce a rising characteristic.

Any error is proportional to transformer load current which means that in a typical two transformer substation, even when the substation is fully loaded, the error is normally reduced by 50%.

In the unlikely event of a system power factor well outside the above range or constantly varying over a very wide range then SuperTAPP relays can be supplied which have a true Circulating Current option. However this method is not recommended for normal use because of the various disadvantages outlined earlier.

8. VOLTAGE TRANSFORMERS

VT's used for voltage control systems may either be connected to the transformer secondary winding, normally at the transformer circuit breaker, or directly to the lower voltage bus-bar.

This guide examines the relative merits of these two alternatives. The conclusions reached can be applied generally to all types of voltage control scheme and not just to the SuperTAPP system.

8.1. Operational Considerations

Whenever a transformer is taken out of service it is essential to provide some means of ensuring it is on a suitable tap position before putting it back on load.

In the case of a Master/Follower system this means that the transformer left in service must always be selected to Master.

This ensures that the transformer to be restored (the follower) will be kept on a similar tap to the master. This method does not, however, always ensure the best result. At medium to high substation loading there will be a significant step increase in voltage at the instant the idle transformer is restored to service due to the voltage drop being suddenly halved.

This effect is more noticeable with increased substation loading and high transformer impedances. In some cases it may be necessary to control the tap-position manually to achieve a suitable result.

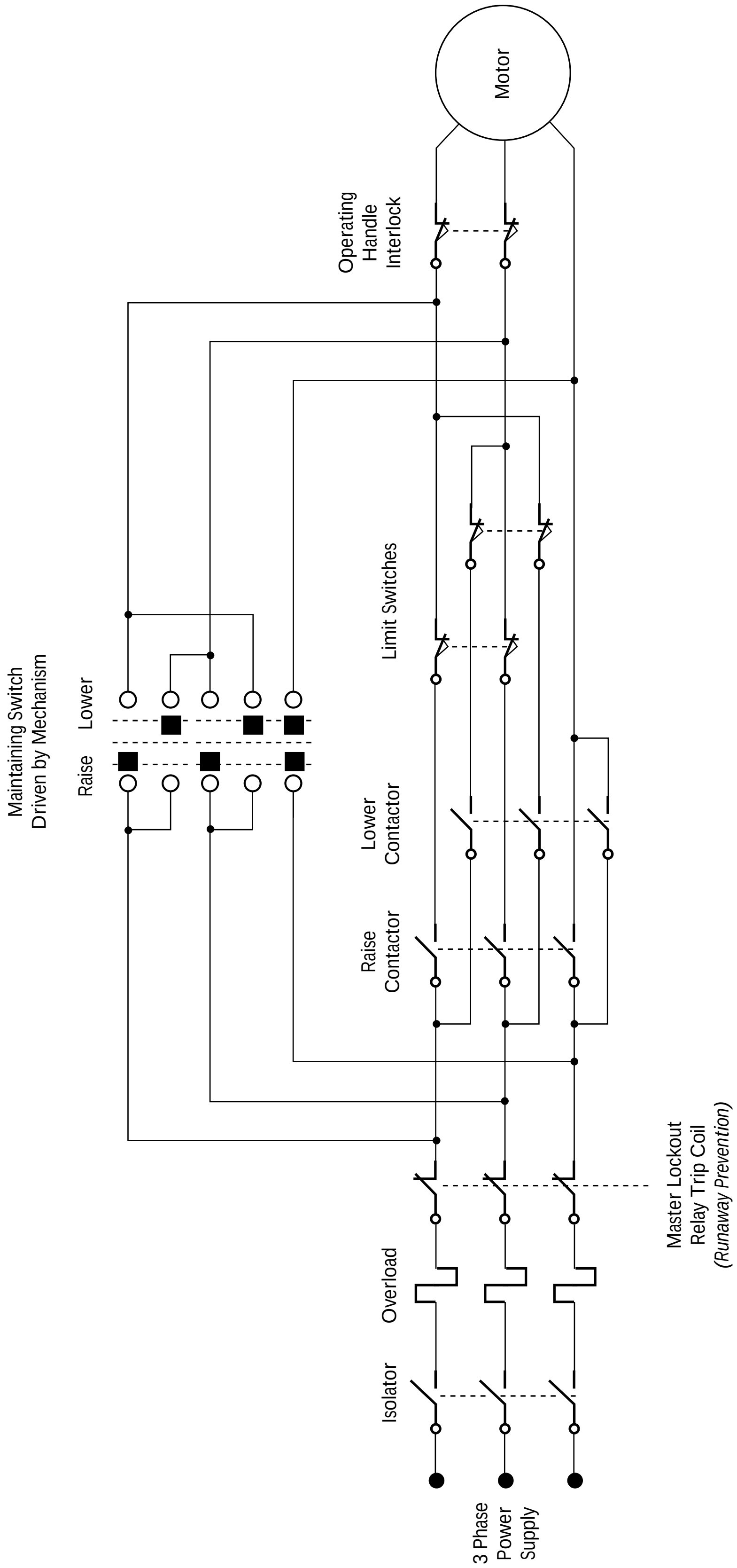
Present-day customers with sophisticated electronic equipment are more sensitive to sudden changes in the level of voltage. If LDC is required the additional loading on the Master when the Follower is off-load produces a double-boost situation unless CT summation is employed.

This step increase in voltage can be eliminated if SuperTAPP relays are used. By allowing the off-load transformer to settle on a tap-position which produces the same output voltage as the loaded transformer (typically 2 to 4 taps lower) there is virtually no change in bus-bar voltage at the instant the idle transformer is restored to service irrespective of substation loading or transformer impedance. This effect can only be achieved if the no-load voltage of the idle transformer can be measured and supplied to the regulating relay. Bus-bar connected VT's are therefore unsuitable for this purpose. In the case of the SuperTAPP system any circulating current which flows after parallelling caused by the small difference in tap-positions is quickly reduced to a minimum by the inherent coupling effect of the relays.

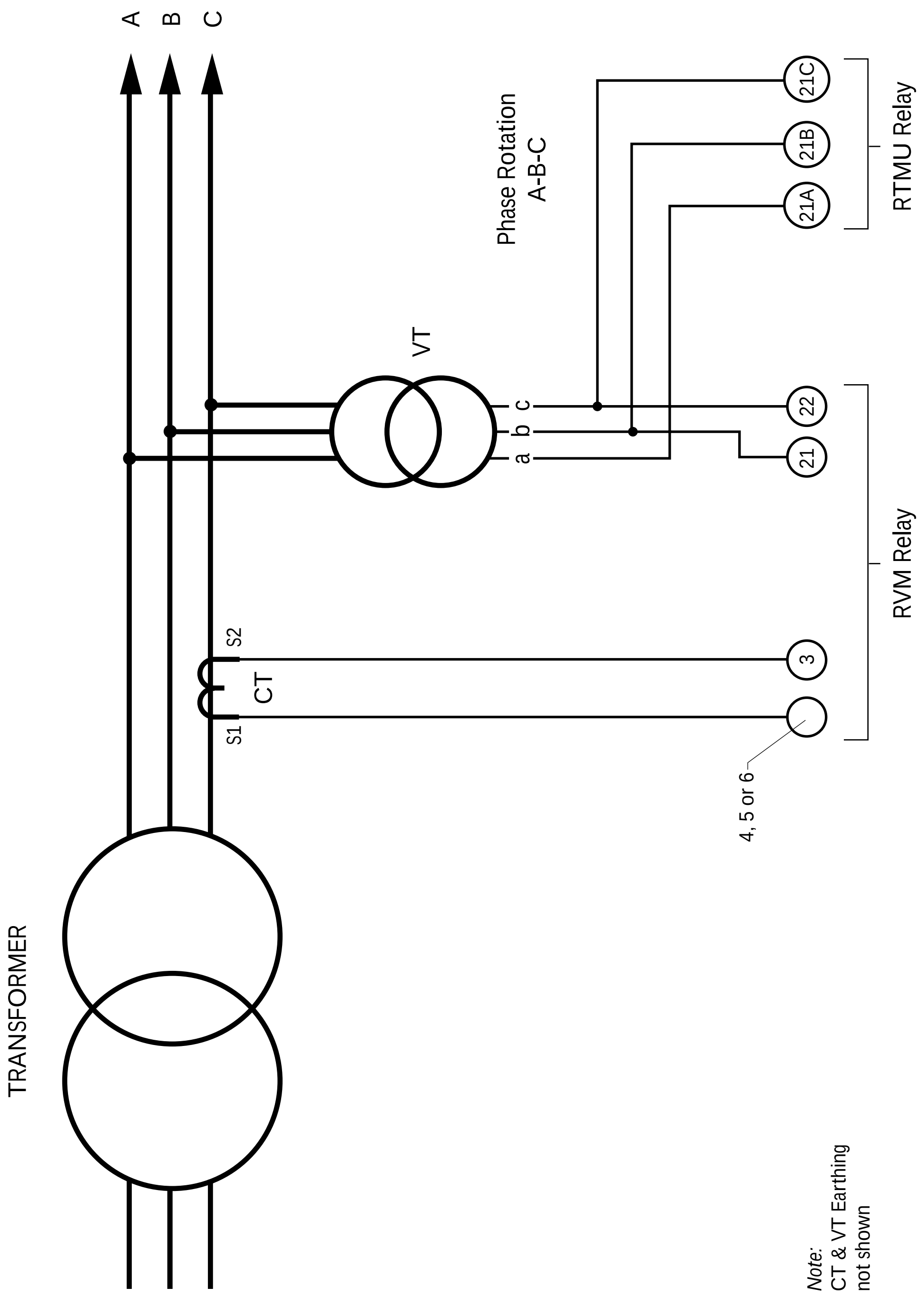
In the case of a bus-bar connected VT it is important to disable a transformer's voltage regulating relay whenever it's secondary circuit breaker is open. If this precaution is not taken the regulating relay will be allowed to control a tap-changer without being able to measure it's output voltage. Thus if the voltage is out of band (or drifts out of band) an unstable situation will arise caused by ineffective raise or lower instructions being issued by the relay to it's tap-changer. The tap-changer will soon arrive at either it's upper or lower limit producing an abnormal voltage. The disabling is achieved either by disconnecting the relay's power supply or more commonly it's VT supply by means of an auxiliary switch in the transformer's lower voltage circuit breaker. For more complex substations further auxiliary switches may be considered to be necessary in the bus-section and/or bus coupler circuit breakers in order to ensure that all possible operating conditions are catered for.

In common with most other voltage control schemes the SuperTAPP system can operate with either bus-bar or transformer connected VT's but the operational restrictions imposed by bus-bar VT's still apply and the ability of SuperTAPP to automatically match secondary voltages before putting transformers back on load (thus avoiding sudden step changes) cannot be utilised.

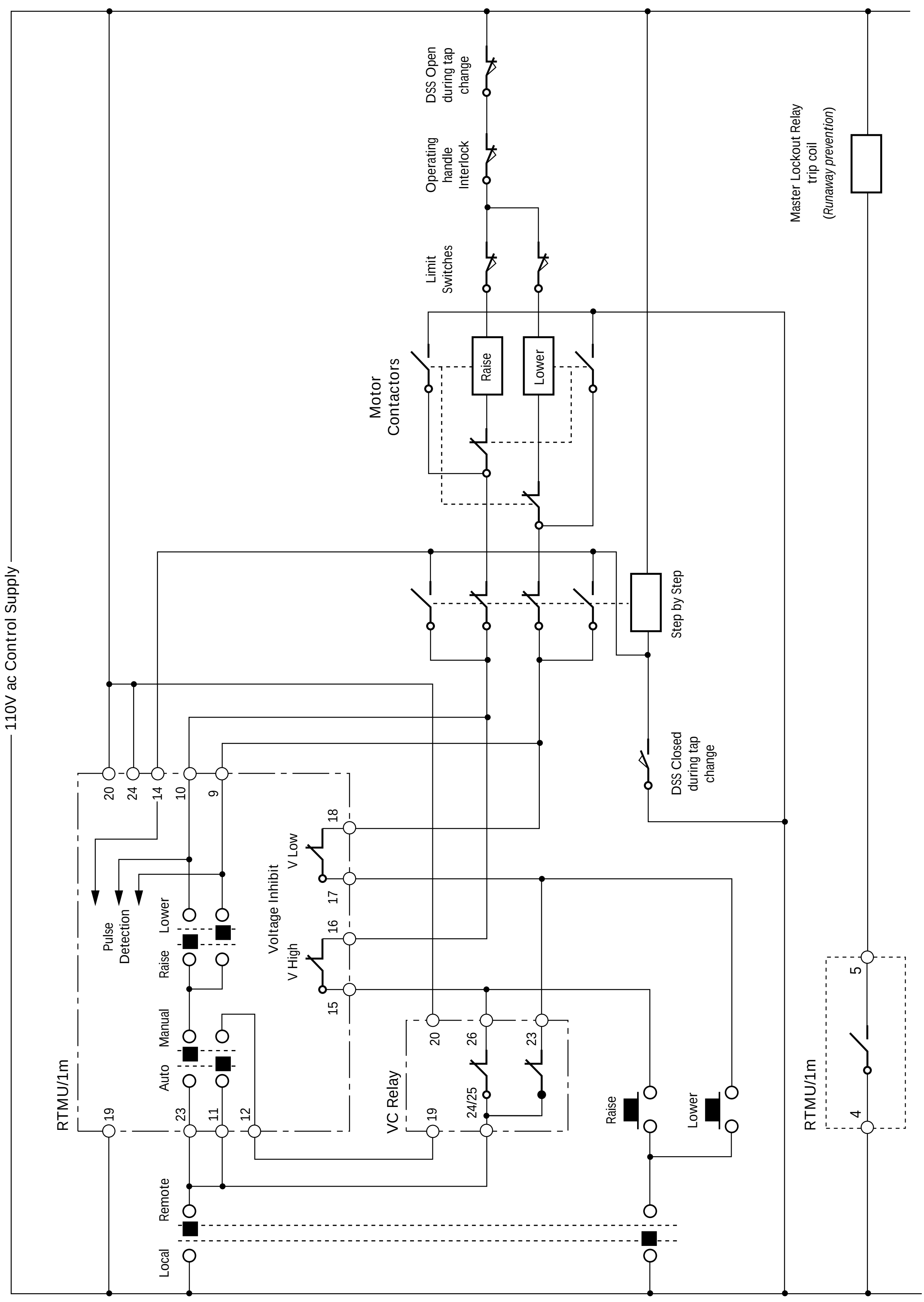
One significant advantage of the SuperTAPP system is that if an idle transformer is inadvertently restored to service on an unsuitable tap position then the inherent coupling features of SuperTAPP relays together with their "fast tap down" feature will quickly restore all transformers at the site to the optimum tap-positions. This applies to both types of VT connection but in particular to bus-bar VT schemes.



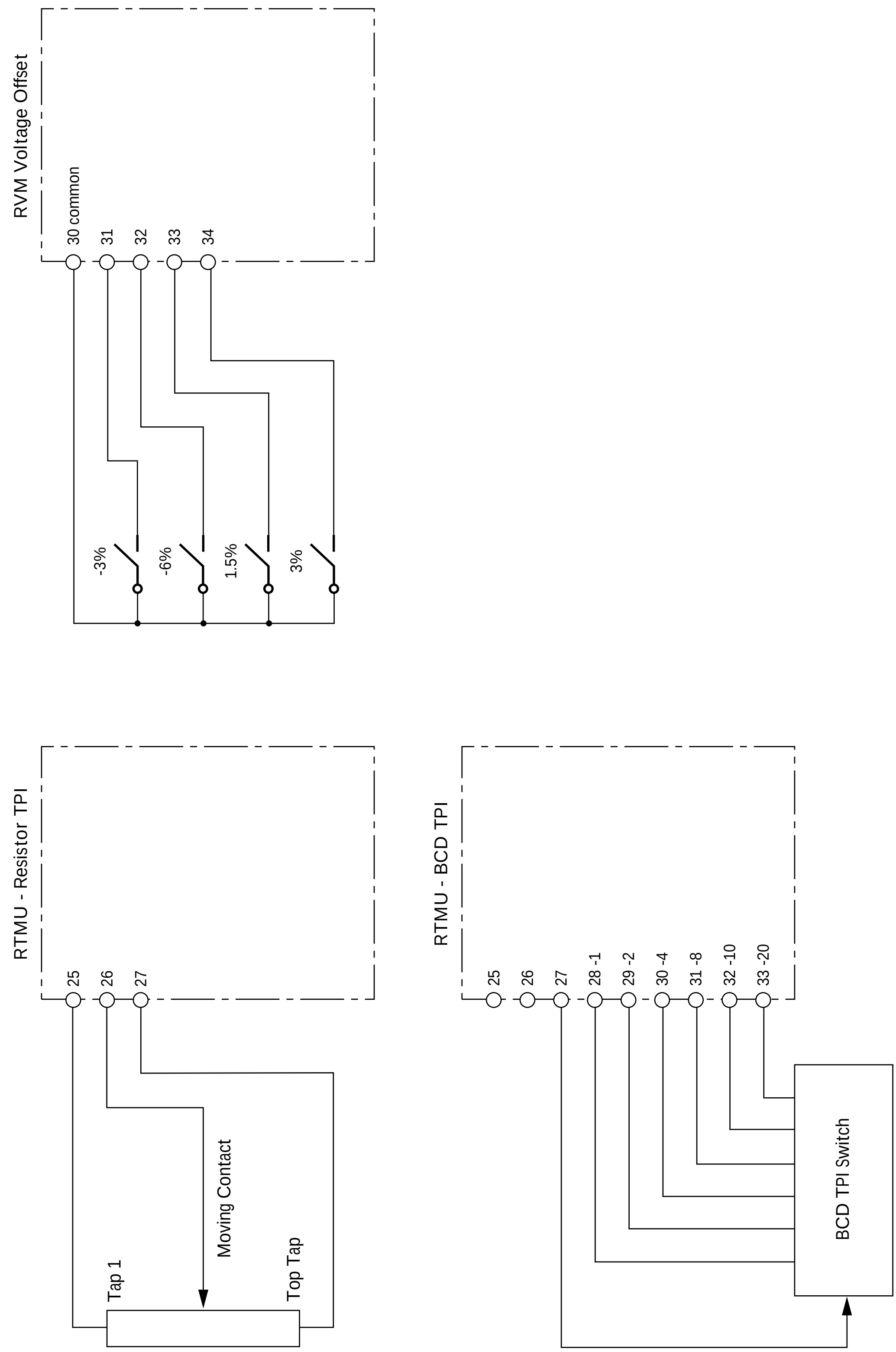
Typical Tap Changer Motor Circuit



SuperTAPP VT & CT Connections



SuperTAPP - Typical Tap Change Control Circuit



SuperTAPP Voltage Offset Connections - Tap Position Indicator Connections