ACCIDENTAL CONTACT BETWEEN DISTRIBUTION LINES OF DISSIMILAR VOLTAGES

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Abstract

The accidental contact between 33kV and 11kV distribution lines is investigated. Experiments conducted on a contrived network showed that during a clash between high voltage and lower voltage conductors, the voltage on the high voltage side is pulled down to the low voltage value. The experimental results were emulated using electromagnetic transient modeling. The modeling was then extended to simulate clashes on a real network as a means of determining settings for protection relays to isolate the excessive fault currents and hence minimise the effects of such incidents.

1. INTRODUCTION

Accidental contact between overhead power lines of dissimilar voltages has become an increasingly common issue. This is particularly so for distribution level voltages where conductors of dissimilar voltages can be strung on the same poles, may cross, or are in close proximity in the same right of way.

Accidental contact can be caused by falling trees, high winds, and earthquakes or from automobile accidents in which a pole is hit. Errors during switching can also lead to such contact. Apart from the damage to power system components, the loss of load to consumers decreases the supply reliability.

The objective of this paper was to investigate the effects of a short circuit between 33kV and 11kV overhead power lines, to determine protection settings for circuit breakers to isolate the fault currents arising from clashes, and minimise the impact of such an incidents.

2. LABORATORY INVESTIGATION

A single phase laboratory investigation was set up to determine what effects could be expected when lines of dissimilar voltages clash. A low voltage circuit was set up as shown in the single line diagram of Figure 1. This circuit consisted of two radial network arms run from a single power supply. Each network arm consisted of an RL hardware model of a distribution line with nominal impedance of 50 + j25 ohm, and a load resistance of 450 ohms. These are relatively high values, but were chosen to keep currents under fault conditions to levels that would not damage equipment.

A 230/24V transformer was inserted in to network arm 1 to simulate conversion of the load voltage on that arm to a lower value. The transformer could be bypassed by switch 1. A second switch 2 was inserted between the load busbars 1 and 2 of the respective arms. When this switch was closed it could be used to simulate an uncleared fault due to a sustained clash.

With Switch 1 closed and the transformer bypassed, the two radial networks are identical. For a supply voltage of 50V, the nominal currents in transmission lines TL 1 and TL 2 were calculated to be 0.1A. The measured values were 0.12A and 49.5V. The load busbar voltages were both 45V. There were minor differences in the values on each arm, indicating that the physical components were not perfectly matched.

With both switches 1 and 2 closed, a connection is provided between the load busbars. The voltages on these busbars were both measured to be 49.5V. The current in the tieline between the load busbars was effectively zero. This is expected as the network arms are essentially balanced and unchanged from the first test.
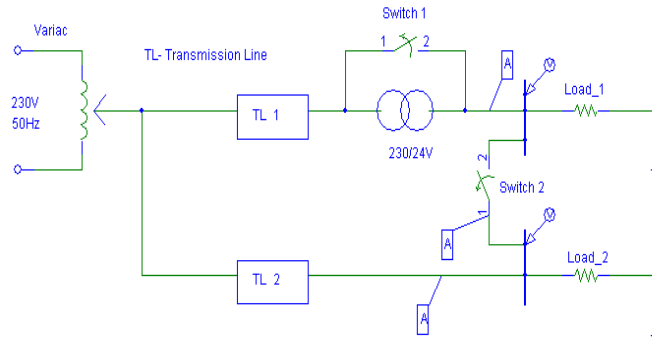
Figure 1: Circuit constructed for laboratory investigations

With Switch 1 and 2 open, the arms were now different, as the transformer was inserted in arm 1. This simulates normal operation where one load is supplied at a lower voltage than the other. As expected, the operation of these arms was independent of each other. The load voltages were 5.6V and 49.5V at busbars 1 and 2 respectively. The respective current flows in the loads were 0.01A and 0.12A.

When Switch 2 was now closed, the condition of a sustained clash was simulated. The voltage on load busbar 1 essentially remained unchanged at a measured 5.6V. The excitation of the transformer remains with the primary side and this dominates over the direct connection of the load busbar 1 to the high voltage supply via network arm 2.

This may initially appear as a counter-intuitive result, however it is understandable in that the supply can be considered as an infinite or fixed voltage busbar. The transformer primary current was measured to be 0.14A, essentially the value under normal operation, which means that the primary voltage is effectively the same as the supply. The transformer ratio is fixed and this forces the secondary voltage to remain low. Thus, instead of the higher voltage network increasing the voltage on the lower voltage network, the voltage on the higher voltage network is pulled down to the lower level. Hence, over-voltages are not likely to be a cause of damage to components on the low voltage network, nor will over-voltage relays detect the fault condition and allow isolation of the situation.

As a result of these voltages, the voltage drop across distribution line 2 increased from about 1V before the clash up to 44V after the clash. The current through this line thus increased from 0.12A to 1.36A. A small component of this current flows to the load. Most of the current, 1.34A, flows into the tie line and into the secondary side of the transformer and through the

neutral system back to the supply. This secondary current has changed dramatically from the 0.01A before the clash, an increase by a factor of >100. The relatively high currents in a real system would need to be sensed by over-current relays and the system components switched out in the event of a sustained fault.

3. COMPUTER MODELLING OF LABORATORY NETWORK

A conventional powerflow program cannot be used to simulate the clash situation as there is a violation of the per unit system when considering a tie line between 2 supplies of different voltage. Instead, an electromagnetic transients program, PSCAD/EMTDC [1], was used to emulate the laboratory experiments. This is a time domain simulation program. However, it could be used for these observations by allowing the system to settle to a steady state condition. For all the cases studied, the simulations were run for 0.1 second.

The specific resistances and inductances for the lines and load were measured using an RLC bridge and entered into the program. The generic transformer model accepts nominal voltages, VA rating and leakage reactance. The latter was measured as 0.03 pu using a short circuit test. The supply was modelled as a voltage source behind a 0.1 ohm series impedance.

The PSCAD model of the system before the clash is shown in Figure 2 (a). This takes into account the measured asymmetries between nominally similar components. The results are presented in Figure 2 (b). The source voltage was specified as 51V rms to give a nominal supply terminal voltage of 50V. A tie line was then placed between the load busbars to represent a clash of the different voltage systems. The simulation results are shown in Figure 3.
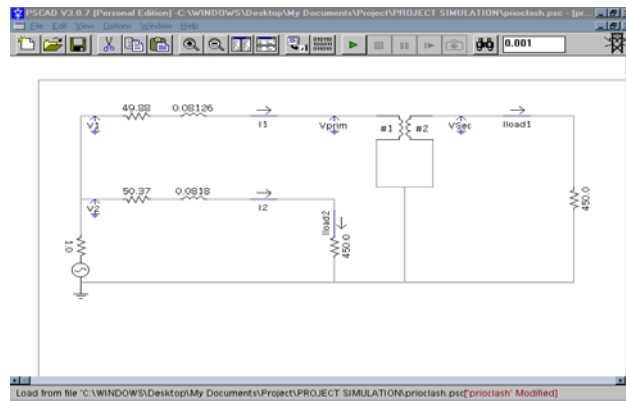
Figure 2(a): PSCAD model of the laboratory investigation

The voltage on the secondary side of the transformer was calculated to be 5.7V, for both before and after the clash. This is similar to the laboratory measurements. The consequent current flows throughout the network, for both situations, were also similar to those measured.

These simulations emulated the laboratory measurements and observations. The electromagnetic transients program could now be used to simulate clashes between actual high voltage systems, where laboratory measurement is impractical, and field measurement untenable.
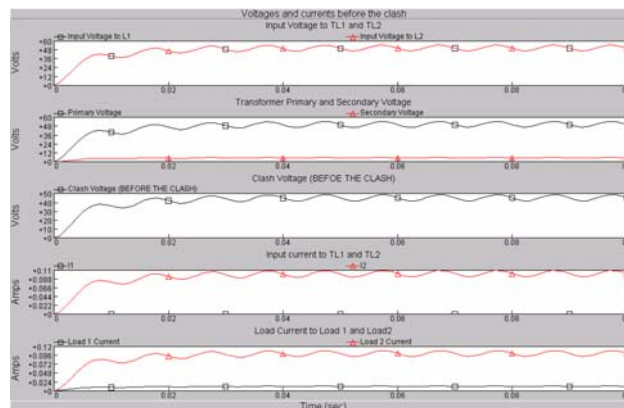

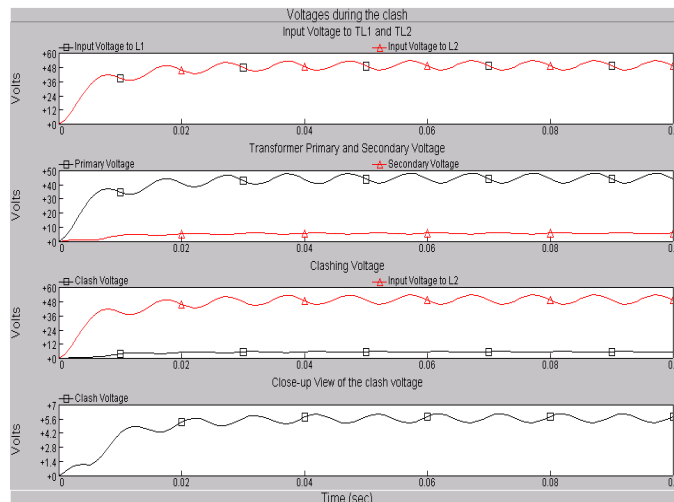Figure 2(b): Simulation results of the system before the clash

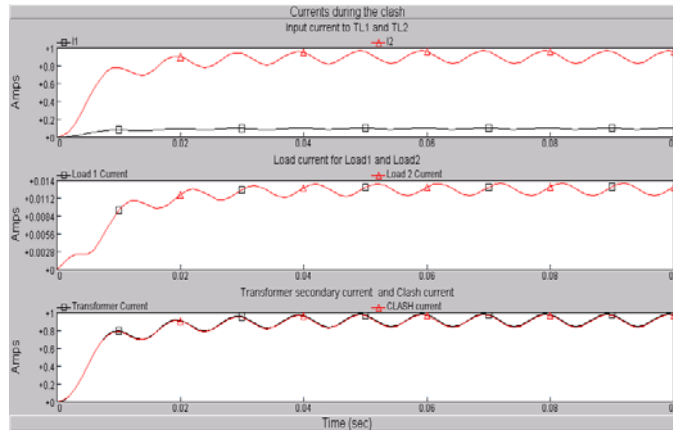Figure 3(a): Voltage waveforms during the clash

Figure 3(b): Current waveforms during the clash.

4. SIMULATION OF THREE PHASE 33KV AND 11KV SYSTEM CLASHES

A three phase network was modelled using PSCAD/EMTDC for simulating the effects of real clashes that can occur between overhead lines, such as that represented in Figure 4, where 33kV lines are slung above 11kV lines.

Figure 4: 33kV overhead distribution lines above 11kV lines with Tee-off to local service 11kV/415V transformer

The simulation model of the radial network from the 33kV point of supply substation to the loads is shown in Figure 5. A 33kV distribution line feeds a 33/11kV transformer and 11kV line, which in turn feeds an 11kV/415V transformer and load.
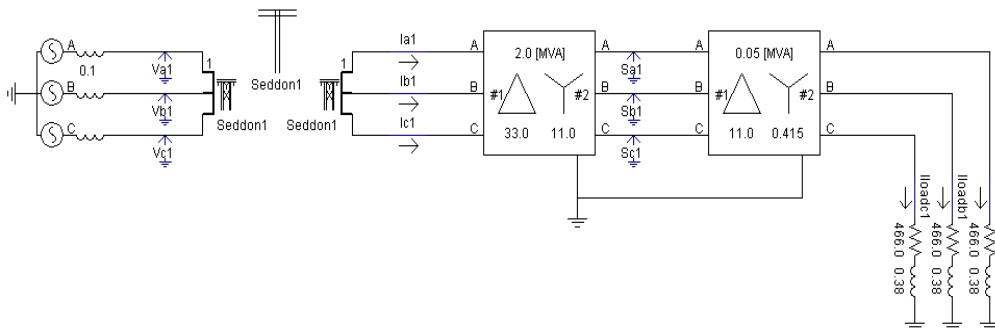

Figure 5: PSCAD/EMTDC model of 33kV and 11kV distribution feeder

The parameters of the distribution lines, transformers, and loads were all representative of a real system in the Marlborough region of New Zealand. For part of their run, the 33kV and the 11kV lines are mounted on the same poles as per the illustration of Figure 4. No account was made of any inherent coupling of the lines as any affects would be minor to the effects of the intended studies.

To simulate single phase clashes between these lines, a low impedance connection was made between one phase of the 33kV line to one phase of the 11kV line. The system was allowed to run to steady-state over a period of 0.1 sec.

For no clashes, the system voltage and current waveforms are presented in Figure 6. These show generally balanced and rated voltage values (on a phase to neutral basis), and the current levels for the loads specified. The imbalance in the 33kV line currents is due to the model of a flat distribution line. Such a model was not used for the 11kV line. Instead, single uncoupled phases were used to facilitate clash connections.

The system conditions that occur when phase a of both the 33kV and 11kV systems clash are presented in Figure 7. These show that the input voltage of the 33/11kV transformer has been pulled down from its nominal value of 19kV to about 9kV. Phase c voltage has reduced to approximately 4.5 kV.

The current flowing in phase a of the 33 kV system has increased from about 2A to 330A, that for phase b to 140A, while phase c current is unaffected. The load currents, while unbalanced, are of much the same magnitude as they were before the clash.
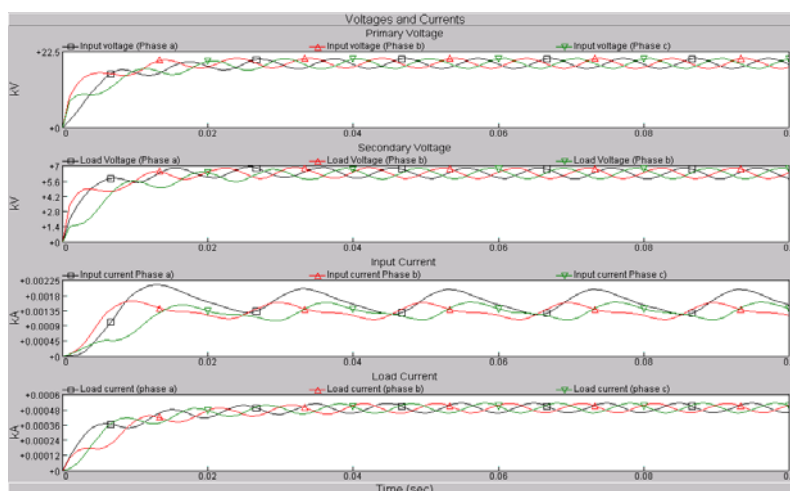

Figure 6: Voltage and current waveforms for system without line clashes.

For phase b-b and phase c-c clashes, the results are essentially similar, with appropriate changes in values of the particular phase voltages and currents. There are 9 different combinations of single phase clashes. All combinations were found to have voltage and current values that lay within a nominal range.

The model could also be used to simulate multiple phase clashes. There are 36 possible combinations of 2 phase clashes. All combinations appeared to have similar characteristics in that for the affected phases, the clash voltage was about 6kV, the nominal phase voltage for the 11kV system. The line current of affected phases was of the order of 500A.

Simulations were also conducted for three phase clashes. For affected phases, the clash voltage levels ranged between about 1kV and 5kV depending on the phase and the asymmetry of the clash connections. The line currents were of the order of 500A, similar to the 2 phase cases.

5. NETWORK PROTECTION

The over-riding results from the laboratory and simulation studies indicate that system voltages decrease to the low voltage system levels rather than increase to the higher excitation level. Thus, over-voltage protection cannot be used to isolate the fault.

In order to protect a network from the disruption of a clash between components of dissimilar voltages, the fault current in affected phases of the higher voltage system should be detected using instantaneous over-current relays. By monitoring the particular phases that experience the over-currents, and the level of

currents that flow, the location and particular characteristics of the clash can be determined.

6. CONCLUSIONS

The accidental contact between distribution lines of dissimilar voltage has been investigated. A hardware laboratory experiment was conducted on a very low voltage, single phase network consisting of two radial arms of lines and loads. A step-down transformer was inserted into one of the arms before a load to simulate the decrease to a lower voltage. Switches were added to the circuit to bypass the transformer and to connect the load busbars of each arm. Thus, there were four possible operating configurations for the network.

The experiments revealed that during a clash between high voltage and lower voltage conductors, the voltage on the high voltage side is pulled down to the low voltage value. Consequently, the current in the higher voltage network increased well above the pre-fault level.

The experimental results were emulated using electromagnetic transient modeling of the single phase system. This allowed extending the modelling to simulate clashes on a three phase 33/11kV network that had component characteristics representative of a real network. Both 2 phase and 3 phase clashes were simulated. In all cases, the high voltage system dropped to the lower voltages, while the affected phase currents dramatically increased.

The simulation provides a means of determining settings for overcurrent protection relays to isolate the excessive fault currents and hence minimise the effects of such incidents.

7. REFERENCES

[1]   PSCAD/EMTDC Version 3, Manitoba HVDC Research Centre Inc., Winnipeg, Manitoba, Canada, 2001.
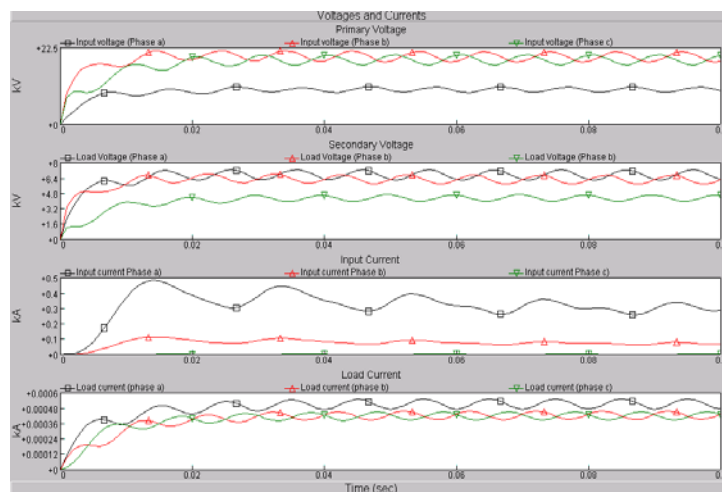
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Figure 7: Voltage and current waveforms for phase a to phase a clash on the 33/11 kV system