Effect of Line Length to Voltage Sag Propagation by Monitoring the Behaviour of Phase Angle Jumps

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Abstract - Occurrences of voltage sag in power system are one of the most major concerns in power quality problem. Power system faults are the largest contributors to voltage sag and phase angle jumps. Three essential characteristics that voltage sag is commonly described which are sag magnitude (voltage during the fault), sag duration and frequency. Power system network consists of different transformer windings configurations and different line length. During fault, transformers winding configuration and line length may affect the propagation of phase angle jumps in a power system network. Thus the intention of this work is to investigate the propagation of faulted voltage to other busbar under an influence of the transformer connections and the effect of line length impedance to the faulted voltages by monitoring the behaviour of phase angle jumps. Power System Computer Aided Design (PSCAD/EMTDC) will be used to construct and simulate a power system test model network. The test system used will allows major variations in network parameter in order to understand its influence on voltage sag propagation.

Keywords-voltage sag, transformer windings configuration line length, phase angle, fault, PSCAD/EMTDC

I. INTRODUCTION

Voltage sags are one of the most major concerns in power quality problem. In supplying the electric supply under the normal operating condition, it is important to ensure that any interruption or disturbance do not happen to the consumer's process. Power quality can be referred as to summarize the interaction between the electrical suppliers, the system and product energized, the consumers and environment. To comply with industries standards, power quality must act more than the delivery the uncontaminated electric power to the consumers. The maintainability of that power, the design, selection, and the installation of hardware and software in the electrical energy system [1]. So, power quality is an indicator of how the components stated before affect the system since from the generation plant until the consumer. Voltage sags are defined as a short duration reductions in rms voltage which caused by short circuits, overloads, and starting of large motors [2]. When the rms voltage drops below 90% for longer than one or two cycles some equipment will trip [2], which means that voltage sag was happened. This is simply can be say that voltage sag is a momentary reduction of the rms voltage magnitude in a range of 0.1 to 0.9 pu together with duration from 0.5 to 30 cycles [3].

The electricity distribution for consumer begins from the generation of electricity at large power plants. Generally, electricity flows from power plants through the transformers and transmission lines. Then, it will flows to the substations and distribution lines and finally to the electricity consumer.

Transmission line basically is important components in power distribution system. Generally, transmission line is a medium to transfer voltage from point A to point B. The length of transmission line will affect the overall performance in distribution the power to consumer. Addition of faults on transmission system and distribution system may cause the voltage sag that increases the effect of distribution performance.

By referring to [4], faults usually occur in a power system due to insulation failure, flashover, physical damage or human error. These faults can happen in either symmetrical or asymmetrical manner which symmetrical will involve three phases while asymmetrical involve only one or two phases. In [4] also stated that faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Sometimes simultaneous faults may occur involving both short-circuit and open-circuit faults. In this paper, asymmetrical faults had been used to identify the difference changes on phase angle jump during sag by monitoring the faulted and loading area in the distribution system. This is due to asymmetrical three phase faults; the transformer connections have a strong effect. And because of that, propagation of voltage sag through transformer to all distribution networks and consumers are also an important thing need to be studies and understand.

Phase angle jump happen when three phase faults are due to the difference in X/R ratio between the source and the feeder [5]. There are some factors that will affect the sag magnitude and phase angle jump at a certain point which are distances to the fault, fault impedance, type of fault, impedance line length and system configuration. This system configuration consists of system impedance and transformer connections. Phase angle jumps are very importance since the relation between sag magnitude and phase angle jumps are dependent and as a continuous function of distance to the fault in a certain line of the system [6]. Phase angle associated with voltage sag problems can propagate and travel to transformer through transmission lines throughout all the distribution system. It is important to monitor the propagation of the phase angle to ensure that the phase angle will not harm consumers and utilities parts.

Thus this work will investigate the behaviour of phase angle jump with respect to different line length to the propagated faulted voltages and will be using the test system in [7] with the addition of transmission lines model.

II. METHODOLOGY

In this research, the effect of transmission lines parameters and transformer winding configurations on voltage sag will be perform in a modeled test system. Test system network will be constructing using PSCAD/EMTDC simulation package. The test system that will be used is the same as [7]. But in addition, transmission lines models will be added to the test system.

Single line to ground fault will be simulated at 33kV busbar. The propagated faulted voltage will be monitor at the load side 415V. Different types of transformer as same in previous studies are used which are Case 1: delta-wye, Case 2: wye-zigzag and Case 3: delta-zigzag. The single line diagram for all cases was shown in Figure 1, Figure 2 and Figure 3 respectively.

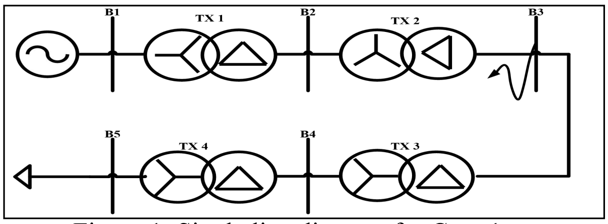

Figure 1: Single line diagram for Case 1

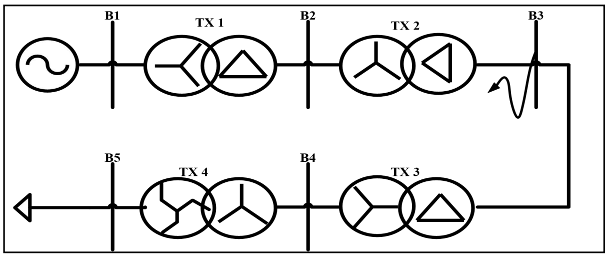

Figure 2: Single line diagram for Case 2

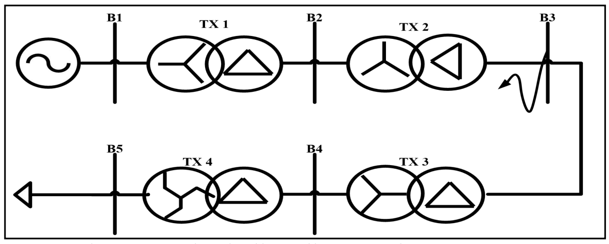

Figure 3: Single line diagram for Case 3

However, the line length will be change in certain parameter which is from 50km to 300km to follow the classification of transmission line length which are short (<80km), medium (80km-240km) and long (>240km). The line length at the faulted busbar will expand. Then, the culpability of the fault event at the neighboring busbar will analyze.

The line length will be expand from 50km to 300 km to see the variation of neighboring busbar experiencing an interruption caused by the fault and increases in voltage and phase angle jumps. The data were tabulated and the graphs were plotted on phase angle at different parameter of line length.

The findings will be concluded by analyzing the tabulated and plotted data of phase angle at different line length.

The methodology of this research can be simplified by the flowchart below:

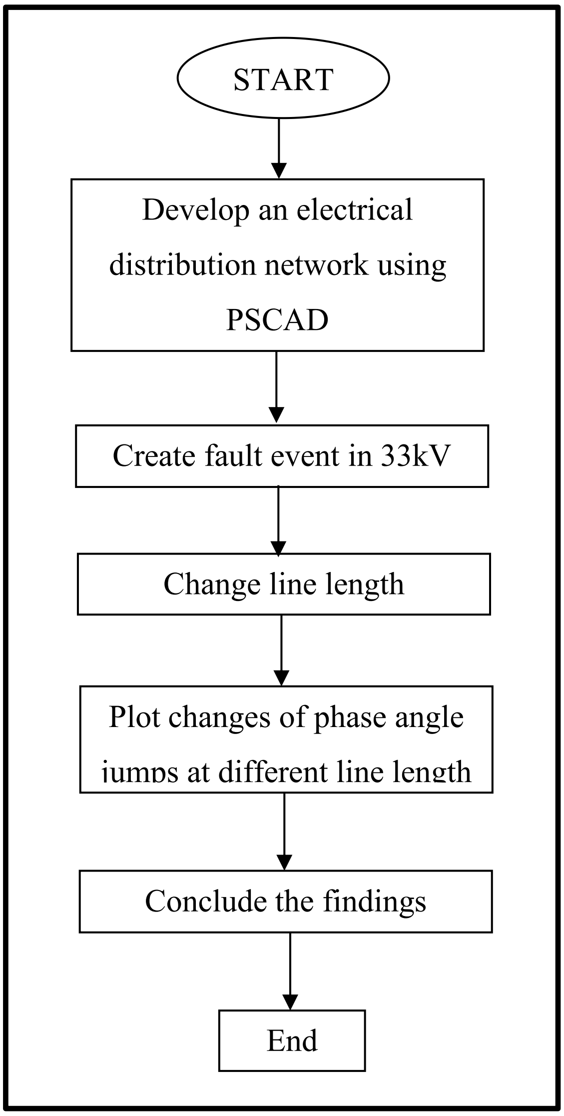

Figure 4: Flow chart of proposed methodology

III. RESULTS AND DISCUSSION

All simulations were done successfully by using PSCAD/EMTDC software. Based on Figure 5-10, the simulation results will be compared based on the plotted graph of phase angle at the difference line length during sag happened. The data were recorded at 33kV busbar and the behaviors of phase angle jump with respect to line length were analyzed at 415kV. Faults will be simulated at 33/11kV for Case 1, Case 2 and Case 3. In this work single line to ground will be simulated because single line to ground fault is the most common fault that occurred in power system network.

A. Case 1

Based on Figure 5, during the sag caused by fault, the graph ploted shows some deviation occur at the phase angle jumps when the line length increase. Since these are the three phase system, the data were recorded based on each phase. Phase *a, b* and *c* shows that the deviation occurred when the line length is 50km to 80 km. Phase *a* also shows the highest deviation when line length increase to 210km. Meanwhile at the same length phase *b* and *c* shows almost no deviation. Phase *b* experienced back the obvious deviation when the line legth is 260km. These shows that the line length gave an effect to the voltage sag propagation due to the deviation in the graph plotted.

After the voltage propagated through the fault 33kV busbar, voltage will propagated pass through the delta-wye transformer before its reach to the load.When the fault occurs, the voltage sag appears on the neighbouring bus. Which mean, it will also affect the load. Based on the Figure 6, the graph plotted is almost linear which shows almost no deviation were occurred at the load of 415V. This is meant that after the voltage propagated through transformer, its shows that the transformer can reduce the effects of sag. In addition, based on [8] says that the three phase transformer with delta-wye connection has a stable neutral point and the interlinked magnetic circuits of secondary neutral to line e.m.f. is free from third harmonic. Plus, the delta-wye transformer is suitable for three-phase transmission and distribution according to [8] since a load taken off between neutral and line will cause the neutral to shift only an amount equal to the impedance drop of the transformer supplying the loaded phase.

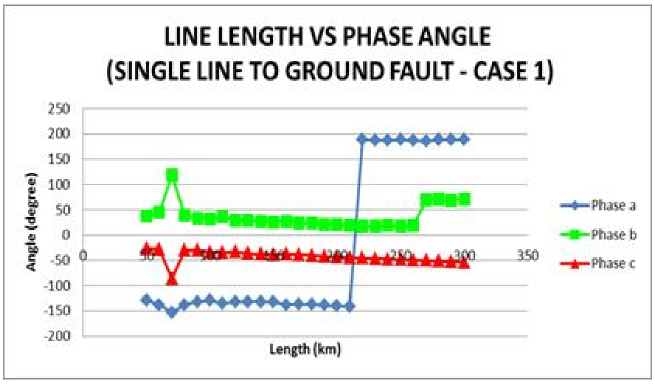

Figure 5: Graph at fault 33kV busbar

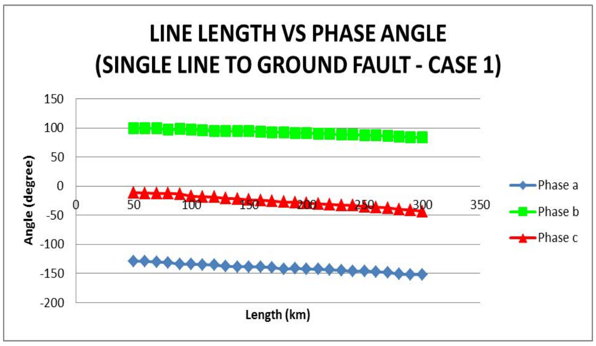

Figure 6: Graph at load 415V

B. Case 2

In Case 2, when fault were simulated, the propagated faulted voltage gave different reading at neighboring busbar and changes at load bus. Figure 7 shows the effect of when sag happen to the phase angle jumps. When the fault of single line to ground applied, there were deviation of phase angle happened through the line length. As shown in Figure 7, phase *a, b* and *c* experienced high deviations through the line length especially phase *c*. The deviation started can be seen at line length of 70km which all the phases angle were decrease. The angles of the three phases increase back at the length of 90km and then decrease again. These happened until the line length is 240km before the graph plotted is almost linear.

Figure 7 experienced difference and higher deviation of phase angle when the line length is increased compared to Figure 5 is due to difference transformer connection which is wye-zigzag. When faulted voltage propagated, changing at load also happened. As shown in Figure 8, the deviations of phase angle through the line length were decreasing tremendously. Once again, the plotted graph shows that the transformer connection can reduce the effect of voltage sag. In addition, from [9] also said that a three phase zigzag-winding transformer connected across a three phase load may mitigate the voltage sag at any one phase of the load. For this case which the transformer winding connection are wye-zigzag, the Figure 8 shows almost no deviation since the characteristics of wye transformer is stable and the zigzag itself may mitigate the voltage sag.

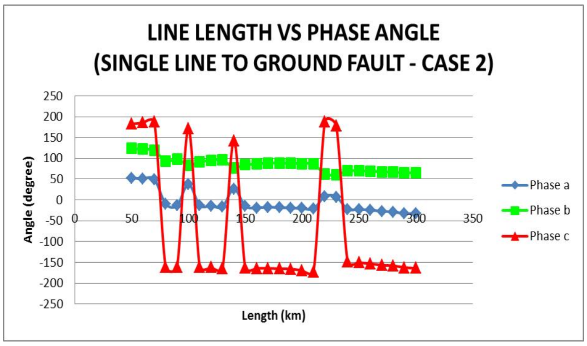

Figure 7: Graph at fault 33kV busbar

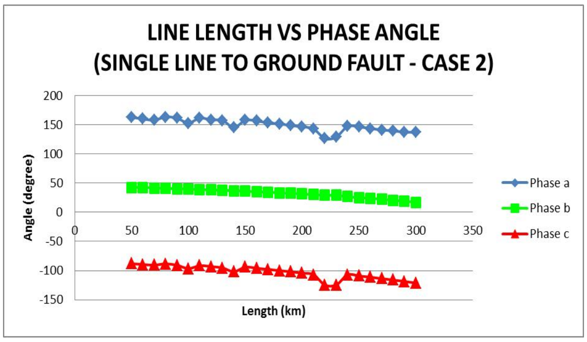

Figure 8: Graph at load 415V

C. Case 3

Based on Figure 9-10, when the fault occur, the propagated faulted voltage will caused different reading at neighboring busbar and changing at load. The plotted graph at fault in Figure 9 shows there were lots of deviation occurred on the phase angle through the line length. The phase *a* shows that the phase angle started to decrease and increase back at the line of 80km, 100km, 140km and 280km. the phase *a* experienced almost no deviation of phase angle at the line length of 150km to 270km. Same goes to phase *b*, where the deviation can be seen as the line length is only 50km. However, the graph plotted for phase *c* shows that the deviation of phase angle through the line length was really unstable. The deviation occurred keep decrease and increase started from 80km until 280km of line length.

Propagated voltage seriously can change the load. Figure 10 shows the deviation of phase angle still happened compared to Figure 6 (Case 1) and Figure 8 (Case 2) which there were almost no deviation occurred. Supposedly, the transformer can reduce the effect of sag due to fault. However, in this case the transformer of delta-zigzag cannot reduce the effect of sag since the deviation still happened at the load. This is due to the transformer or the system itself was unstable. Plus, in [9] already said that zigzag-winding transformer may mitigate the voltage sag at any one phase of the load. So, the plotted graph in Figure 10 proves that the transformer connection cannot mitigate the sag well at phase *a* compared to phase *b* and *c*.

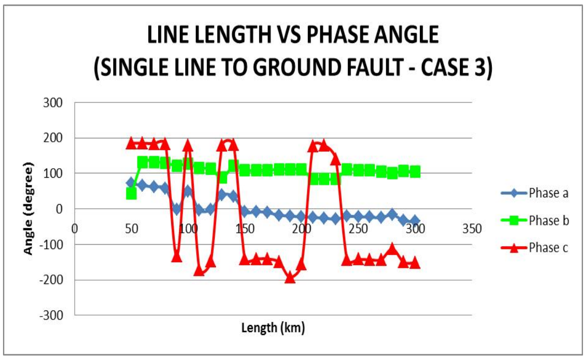

Figure 9: Graph at fault 33kV busbar

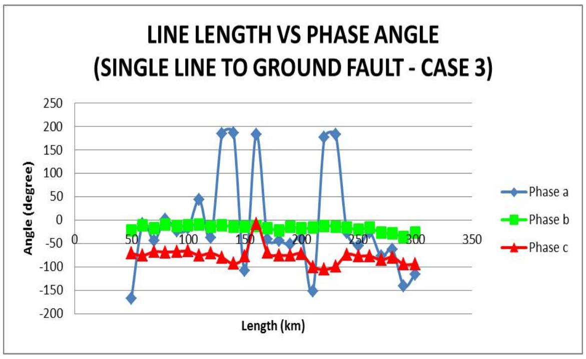

Figure 10: Graph at load 415V

IV. CONCLUSION

This paper has investigated the changes of phase angle due to the changes of line length impedance to the propagated faulted voltages and the effect of transformer windings connection to the system on the propagation of voltage sag. This paper has shown that sag happened will affect the consumer. From the simulation that had been done, the sag occurred due to the fault may be able to be mitigated by the transformer connection even though the line length is increase.

Transmission line acts as a resistance to the whole system. When the line length increases, the voltage can be more drop than it's supposed to be since the line length act as resistance when voltage propagated, plus with the sag occurred due to the fault that also drops the voltage. When the voltages drop, it will affect the sag magnitude and also the phase angle jumps. The increments of line length make the affect to phase angle jumps worse. These can be seen at the simulation done at the graphs plotted at the fault where there is deviation at phase angle through the increment of line length.

Phase angle associated with voltage sag problems can propagate and travel to transformer through transmission lines throughout all the distribution system. Due to this, the propagated faulted voltage had been monitor at the load side 415V to see the behavior of the phase angle jumps. The results show that the transformer can reduce the effect of voltage sag where there is almost no deviation or the increasing of deviation at phase angle jump with respect to the increment of line length.

This study successfully investigates that the differences of transformer connections will give different changing at the load even though the line length was increases. From the investigation, it has been found that the delta-wye transformers connection can mitigate the deviation of phase angle jumps with respect to line length well. This can be seen where almost no deviation happen to the phase angle through the increases of line.

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