DISTRIBUTION GENERATOR INFLUENCE ON MEDIUM VOLTAGE NETWORK CIRCUIT BREAKERS

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ABSTRACT

This paper deals with estimation of distribution generator influence on medium voltage distribution network equipment. Adding new "green" generators in distribution networks changes their operation parameters. In this paper are specially considered effects on switchgear – breakers. There are two effects caused by distribution generator adding: 1) increasing short circuit current value and 2) increasing aperiodic time constant (if the aperiodic time constant exceeds the value of 45 ms, this can potentially cause problems in breaking of the current). The main goal is to investigate influence of one real 1.1 MVA generator inserted in 10 kV network. Besides the real situation, in the paper are investigated some hypothetic cases in order to estimate expected values for a potential operation.

1. INTRODUCTION

Embedded, dispersed or "green" generators are very widespread in the world because they mostly use renewable energy sources (energy of wind, water or sun) for production of electric energy. Also, these generators are helping to reduce substantial emissions of carbon-dioxide in order to help respond to climate change (global heating of Earth). Considering the high prices of electric energy due to limited quantity of fossil fuels in the future (coil, natural gas, petrol), it is obvious that interest in green generators will rise. In our country, in the last few years, interest in green generators is growing especially in large factory plants where it is possible to use technology process for production of electric energy. This paper deals with influence of green generators on MV switchgear in distribution network [1,2]. The observed green generator is connected to 0.4 kV network in one factory and serves as energy supply.

2. TECHNICAL CHARACTERISTICS OF GREEN GENERATOR AND CONNECTION TO THE DISTRIBUTION NETWORK

In order to estimate impact of a generator on distribution network, one real situation has been used as basis for further considerations. Plant for electricity production has two parts: synchronous generator and motor engine (see picture 1). Synchronous generator is rated 1.1 MVA, voltage 0.4 kV. Fuel for motor engine is gas, which is a collateral technology product of the factory. Speed of synchronous generator is 1500 turns per minute, with excitation current 3.7 A and voltage 64 V. The output gas temperature is over 120 degrees and can be used for heating rooms. Coefficient of efficiency is 86.5% (40% is electrical output and 46.5% is heating output).

Picture 1. – Embedded generator

Generator is connected to both 10 and 20 kV distribution network through energy transformer 10(20)/0.4 kV (transformer with two-rated primary voltage) 1600 kVA. The transformer is connected to 10 kV distribution network through a cable XHP 48 A 3x1x150 mm^2 and 10 kV overhead lane ACSR 3x50 mm^2 whose length is 2800 m. Energy transformer is connected with 20 kV distribution network thru cable XHP 49 A 3x1x150 mm^2 and 20 kV overhead line ACSR 3x95 mm^2 whose length is 5000 m. Main goal is to analyse effects of connection generator through energy transformer 10(20)/0.4 kV. Also, goal is to analyse effects of using a 10 kV generator which is connected directly to 10 kV distribution network, or to 20 kV network through 10/20 kV energy auto transformer. Hence, there are four possibilities:

- Connection of 0.4 kV generator to 10 kV distribution network using 10/0.4 kV energy transformer.
- Connection of 0.4 kV generator to 20 kV distribution network using 20/0.4 kV energy transformer.
- Direct connection of 10 kV generator to 10 kV distribution network.
- Connection of 10 kV generator to 20 kV distribution network using 10/20 kV energy auto transformer.

In each of these cases, generator influence on 10 and 20 kV circuit breakers at the beginning of feeder will be analyzed.
10 kV generators can be provided easily in distribution networks. Standard 10 kV asynchronous motors can operate in generation regime and in such a way this machine will become a 10 kV asynchronous generator (to provide a generator regime, it is necessary to drive motor over synchronous speed). It is irrelevant whether generator is synchronous or asynchronous, the goal is to analyze the effects of such connection.

In the following chapters are given the basics for calculation of aperiodic time constant of fault current, examples, conclusion and literature which is used in this work.

3. GENERATOR INFLUENCE ON CIRCUIT BREAKER EFFICIENCY

Aperiodic time constant of fault current increases due to introduction of generators [1,2]. Simultaneously, total amount of fault current, which consists of alternating and direct fault current, also increases. In this way circuit breaker efficiency decreases. If the aperiodic time constant of fault current overreach value of 45 ms, it can potentially cause problems in current breaking. In this paper is calculated total aperiodic time constant for every type of connection. Method of equivalent time constant is used for calculation. If the generator is connected directly to the feeder, aperiodic time constant is calculated according to this equation:

$$T_{a\,total} = \frac{L_{total}}{R_{total}} = \frac{L_{line} + L_g}{R_{line} + R_g} = \frac{\frac{1}{\omega} \cdot l \cdot x_{line} + \frac{1}{\omega} \cdot \frac{X''_g \cdot V_{ng}^2}{100 \cdot S_{ng}}}{l \cdot r_{line} + \frac{1}{T_{ag}} \cdot \frac{1}{\omega} \cdot \frac{X''_g \cdot V_{ng}^2}{100 \cdot S_{ng}}} \qquad (1)$$

where is:

L_{total} – total inductance of feeder with generator;
R_{total} – total resistance of feeder with generator;
L_{line} – inductance of line;
R_{line} – resistance of line;
L_g – inductance of generator;
R_g – resistance of generator;
r_{line} – resistance overhead/cable line [Ω/km];
x_{line} – reactance overhead/cable line [Ω/km];
l – length of feeder from the beginning up to the point of generator connection;
X''_g – subtransient reactance of generator [%];
V_{ng} – rated voltage of generator[V];
S_{ng} – rated power of generator[VA];
T_{ag} – aperiodic time constant of generator [s];
ω – angle speed which is 314 rad/s;

If generator is connected to the feeder through energy transformer, aperiodic time constant is calculated by this equation:

$$T_{a\,total} = \frac{L_{total}}{R_{total}} = \frac{L_{line} + L_{ET} + L_g}{R_{line} + R_{ET} + R_g} = \frac{\frac{1}{\omega} \cdot l \cdot x_{line} + \frac{X_{ET}}{\omega} + \frac{1}{\omega} \cdot \frac{X''_g \cdot V_{ng}^2}{100 \cdot S_{ng}}}{l \cdot r_{line} + R_{ET} + \frac{1}{T_{ag}} \cdot \frac{1}{\omega} \cdot \frac{X''_g \cdot V_{ng}^2}{100 \cdot S_{ng}}} \qquad (2)$$

where is:

L_{ET} – inductance of energy transformer;
R_{ET} – resistance of energy transformer;
X_{ET} – reactance of energy transformer.

Equations (1) and (2) are used in every example of generator connection. Parameters of generator needed for the calculation are:

X''_g=15%,
T_{ag}=130 ms (this value is picked as average value from 120 ms up to 250 ms – value is proportional to power of generator).

4. EXAMPLES OF CALCULATION OF TOTAL APERIODIC TIME CONSTANT OF FAULT CURRENT

In the example of connection 0.4 kV generator to 10 kV feeder thru energy transformer 10/0.4 kV (see picture 2) equation (2) is used for calculation. Before this calculation is necessary to calculate inductance and reactance of energy transformer through which the generator is connected. Next equations are needed for this calculation:

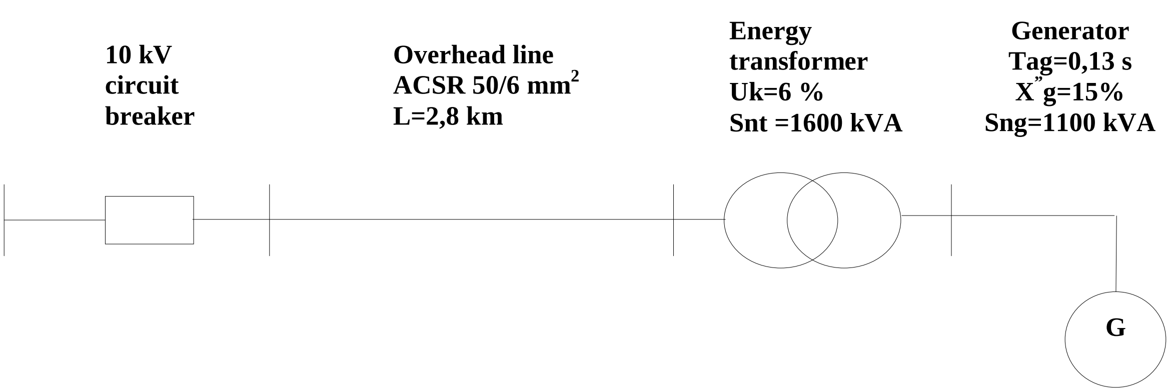
$$Z_{ET} = \frac{u_k \cdot \left(V_{n1}^T\right)^2}{100 \cdot S_n} \qquad (3)$$

$$R_{ET} = \frac{\left(V_{n1}^T\right)^2 \cdot P_{Cu}}{S_n^2} \qquad (4)$$

$$X_{ET} = \sqrt{Z_{ET}^2 - R_{ET}^2} \qquad (5)$$

where is:

u_k – short circuit voltage of energy transformer (%);
V_{n1}^T – rated voltage of energy transformer (V);
S_n – rated power of energy transformer (VA);
P_{Cu} – rated cooper losses of energy transformer (kW);



Picture 2. – Scheme of 0.4 kV generator connection to 10 kV feeder

Resistance and reactance of energy transformer are:

R_{ET}=0.77 Ω
X_{ET} = 3.67 Ω

Finally, the value of total aperiodic time constant of fault current in this example is:

$T_{atotal} = 6.27$ ms

This value is less then 45 ms, so the generator connected to 10 kV feeder in this example doesn't have any influence on work of 10 kV circuit breaker at the beginning of feeder.

If generator is connected to 20 kV feeder trough 20/0.4 kV energy transformer, the values of resistance and reactance of energy transformer are (equation (3),(4),(5)):

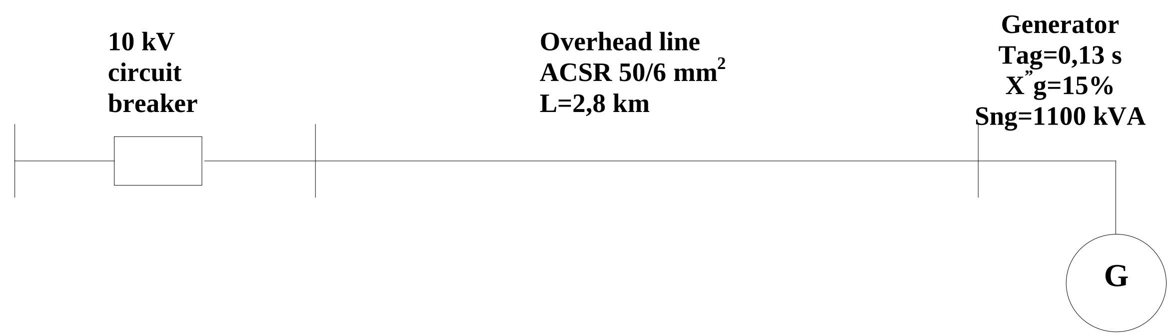
$R_{ET} = 3.093\ \Omega$
$X_{ET} = 14.677\Omega$

The value of total aperiodic time constant of fault current in this example is:

$T_{atotal} = 11.35$ ms

This value is two times greater then value in first example, but still less then 45 ms.
If 10 kV generator is connected to kV feeder, no energy transformer is needed (see picture 3.). Equation (1) is used for calculation of total aperiodic time constant of fault current. The value of total aperiodic time constant of fault current in this example is:

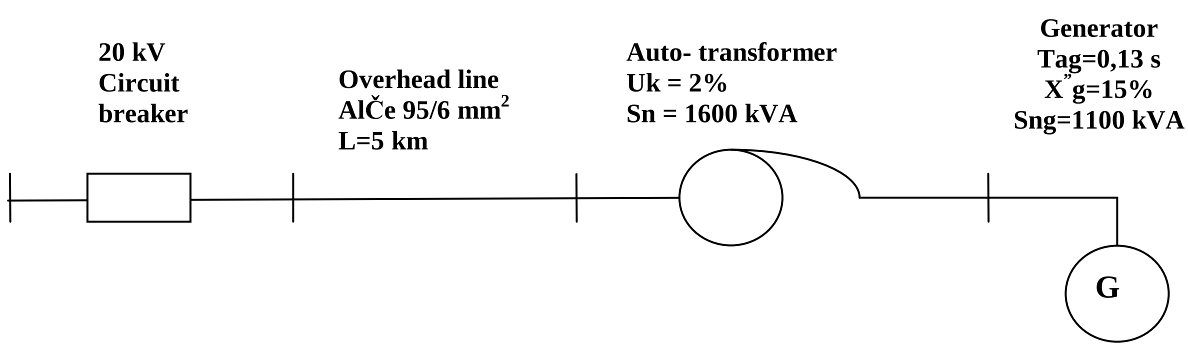
$T_{atotal} = 25.3$ ms



Picture 3. – Scheme of 10 kV generator connection to 10 kV feeder

It's obvious that this value is much greater then value in first and second example, but still it is less than 45 ms.

Last example is connection of 10 kV generator to 20 kV feeder through auto energy transformer 20/10 kV (see picture 4.). This transformer is much cheaper then standard energy transformer of the same power.



Picture 4. – Scheme of 10 kV generator connection to 20 kV feeder

The values of resistance and reactance of auto energy transformer are (equations (3),(4),(5)):

$R_{AT} = 0.3125\ \Omega$
$X_{AT} = 4.99\ \Omega$

The value of total aperiodic time constant of fault current in this example is (equation (2)):

$T_{atotal} = 29.8$ ms

In this example the value of total aperiodic time constant of fault current is still less than 45 ms, but the difference between these values is significantly less (value of total aperiodic time constant of fault current is close to limit value which is 45 ms).

5.CONCLUSION

In this paper is illustrated influence of generators on 10 and 20 kV circuit breakers. This influence is described thru increase of total aperiodic time constant of fault current.

In the first two examples, 0.4 kV generator is connected to a 10 and 20 kV feeder in the way it was done in the plant. In second two examples, this paper deals with hypothetical examples of connecting 10 kV generator via 10 and 20 kV feeder. This way of connection needs more investments in equipment (auto energy transformer and 10 kV generator).

Total aperiodic time constant of fault current is very small in the first two examples, which means that the influence on operation of 10 and 20 kV circuit breakers is insignificant. In the second two examples constant is higher - value of total aperiodic time constant of fault current is close to limit value which is 45 ms.

It isn't hard to conclude that adverse influence of generator on 10 and 20 kV circuit breakers is more significant when generator is connected to a higher voltage level (10 kV generator). Also, the connection of 10 kV generator through auto transformer to 20 kV feeder is more adverse then connection of the same generator on 10 kV feeder directly. The difference between value of total aperiodic time constant of fault current in last example and limit value which is 45 ms is small. Finally, regarding the great length of 10 and 20 kV overhead lines (great distance between generator and circuit breakers) it is clear that this way of connection is very convenient for operation of circuit breakers.

These facts confirm the need for calculation and review of total aperiodic time constant values of fault current.

6. LITERATURE

1. D. Bekut, S. Mandić: Generator Impact on breakers and protection in distribution network (in Serbian), *Elektrodistribucija* 2005., no. 1, pp. 66 – 75.

2. S. Mandić: *Influence of embedded generators on circuit breakers and relay protection in distribution networks, (MS thesis),* Faculty of engineering, University of Novi Sad 2006.