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DETERMINATION OF THEVENIN'S EQUIVALENT MODEL AT THE RECEIVING NODE

This paper presents the properties of the equivalent Thévenin's model of a network as seen from a network receiving node. Such a simplified model can be applied in protective and preventive gear installed at the considered receiving node. Thévenin's circuit can be determined either from of the power system configuration diagram or by use of algorithm based on local current and voltage phasor measurements. Local measurements are used to calculate the derivative of apparent power against the voltage d*S*/d*V*. Paper describes the d*S*/d*V* algorithm accuracy tests according to the approximate angle of the series system impedance. An important problem of the Thévenin's model updating due to the changing configuration of power system is discussed in the paper. The advantages and disadvantages of both described methods are also presented

1. INTRODUCTION

Commonly the analysis of power flow in the power system is based on a full system model. The model contains complete information about the current system configuration (state of switches, power lines and transformers). Assuming the symmetry of loads and generators the model is represented as single-phase circuit. Based on such model full analysis of system security may be determined including calculation of the theoretical lines load and margins of global and local stability. In the full model disturbances occurring during the normal operation e.g. a line switch off for service as well as emergency disturbances may also be analyzed. However, the full system models, in spite of obvious advantages, have numerous disadvantages which make it unfeasible in many applications. The main disadvantage is the previously mentioned

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requirement of knowledge of the full network configuration. Another one is the number of possible incidents that may have the impact on the considered system node and the time required for analysis. Usually, the current configuration of the power system is known to the transmission system dispatcher only so it is impossible to apply the full model in protective and preventive devices. When there is a need to analyze the condition of node by using local measurements the equivalent Thevenin's model can be very useful. This paper presents the characteristics and the possibilities of such a Thevenin's model as well as its determination and updating.

2. THEVENIN'S MODEL DETERMINATION AND UPDATING

2.1. DETERMINATION OF THE MODEL

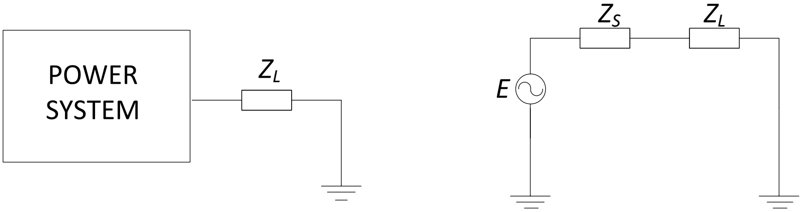

Fig. 1. Power system model and its Thevenin's equivalent

Thevenin's circuit includes: ideal voltage source E, series system impedance Z_S and load impedance Z_L or alternatively load admittance Y_L. Example of a full model and its Thevenin's equivalent is shown in Fig. 1. To calculate the parameters of the Thevenin's model several methods can be used. The paper presents two selected methods. The first well known method is based on a network configuration and parameters of devices installed on power system. The second one, developed by the authors, employs a local measurements of current and voltage phasors.

a) According to the first method the series impedance is calculated using fundamental circuit simplification rules for all voltage sources grounded. The source voltage is the voltage that occurs in the node considered in 'no load' conditions.

b) In the second method the of Thévenin's circuit parameters calculation algorithms are based on local measurements. The algorithm considered in the paper and applied to the Thévenin's circuit from Fig. 1 is defined by the following formulas [1, 2]:

$$V = \frac{E}{\sqrt{1 + 2W\cos\beta + W^2}} \tag{1}$$

$$S=\frac{E^2}{Z_S}\frac{W}{1+2W\cos\beta+W^2} \tag{2}$$

where: V – voltage at the node, S – apparent power in the load, E – equivalent source voltage, Z_S – equivalent series system impedance, $W=Y^*Z_S$, Y – load admittance, $\beta=\varphi_S-\varphi_L$, φ_S and φ_L –system and load impedance phase angles, respectively.

Differentiating formulas (1) and (2) one gets:

$$\frac{\mathrm{d}V}{\mathrm{d}W}=\frac{-V^3\left[\cos\beta+W\left(1+\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)\right]}{E^2} \tag{3}$$

$$\frac{\mathrm{d}S}{\mathrm{d}W}=\frac{S^2\left[1-W^2\left(1+2\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)\right]}{E^2Y_LW} \tag{4}$$

Dividing the equations (3) by (4) one obtains:

$$\frac{\mathrm{d}S}{\mathrm{d}V}=-\frac{1-W^2\left(1+2\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)}{W\left[\cos\beta+W\left(1+\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)\right]}\frac{S}{V} \tag{5}$$

Derivative dS/dV may be used to determine the value of parameters of Thevenin's circuit but also as an indicator of the stability margin. Solving the second order equation, W may be calculated from formula:

$$W=\frac{-\frac{\mathrm{d}S}{\mathrm{d}V}\cos\beta-\sqrt{\left(\frac{\mathrm{d}S}{\mathrm{d}V}\right)^2\cos^2\beta-4\frac{S}{V}\left[\frac{\mathrm{d}S}{\mathrm{d}V}\left(1+\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)-\frac{S}{V}\left(1+2\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)\right]}}{2\left[\frac{\mathrm{d}S}{\mathrm{d}V}\left(1+\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)-\frac{S}{V}\left(1+2\frac{\mathrm{d}(\cos\beta)}{\mathrm{d}W}\right)\right]} \tag{6}$$

Factor W is equal to $Z_S{}^*Y$. So from the equation (6) value of series system impedance Z_S can be directly specified. Formula

$$E = V\sqrt{1 + 2W\cos\beta + W^2} \tag{7}$$

defines value of voltage source E by using W factor. It should be noticed that for an idle node $Y=0$ so also $W=Y*Zs=0$. Thus the node voltage value is equal to voltage source in Thevenin's circuit $E=V$. It is also true for equation (7).

Thevenin's model parameters determined by algorithm which employs the derivative dS/dV correspond to the current system configuration. However, to define these parameters the information about states of the power system components is not required. To calculate the series impedance Z_S and voltage source E the following quantities should be measured: S – apparent load power, V – node voltage and load parameters, namely, magnitude and angle of load impedance. All values in equation (6) can be calculated using measurements except φ_S - angle of system impedance. This angle can be determined using the full model. Small fluctuations of system impedance angle with respect to its assumed average value do not cause significant errors.

2.2. REAL TIME UPDATING OF THE MODEL

Configuration of the power system is not fixed. It is continuously changing due to switching or disconnection of the system components. Such operations are taking place during normal operation and also during faults. Operations that impact the elements of Thevenin's model are the connection or disconnection of power lines, transformers as well as significant loads.

Thus the Thevenin's model based on the first method should continuously be updated. According to the Thevenin's rule each fragment of the power system can be replaced by a series system impedance and voltage source. Using this principle base the full model can be slightly simplified by replacing the distant parts of the system by the impedance and source. To approximate parameters of Thevenin's equivalent there is no need to know entire power system configuration but only the state of the elements that have the greatest impact on the series system impedance. An example of such a simplification can be a fragment of power system connected to node with one power line. In case of receiving information about disconnection of a given power line, information about area that has been disconnected is unnecessary. In the future, when the Smart Grid technology will be developed, access to global data will be fully disposable. Then, this method will give very accurate results.

As it has been written earlier, the algorithm that calculates the Thevenin's model parameters using dS/dV derivative does not require system configuration data. Local measurements of current and voltage phasors are sufficient. This is a big advantage when the data about system are not known for the node considered. The major disadvantage of the method is the need of changing the load admittance to make calculation of Thevenin's circuit parameters possible. This disadvantage is patched automatically.

When system impedance changes the node voltage increases or decreases. The voltage change causes transformer tap changer acting. Activation of tap changer changes load admittance. Another disadvantage is the difficulty of determining the angle of series system impedance.

3. SOME PROPERTIES OF THEVENIN'S EQUIVALENT MODEL

To study the properties of Thévenin's equivalent and accuracy of *dS/dV* algorithm the full model and its equivalent shown in Fig. 2 were used.

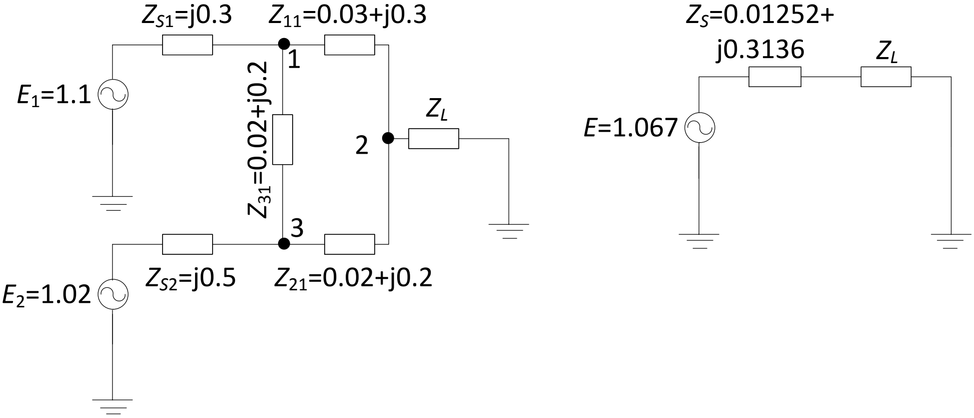

Fig. 2. Test of the full model and its Thévenin's equivalent

Fig. 3 shows the nose curves received by using the full model and simplified Thevenin's circuit. Curves are exactly the same. The differences between them are at level of 10^{-3} and caused by rounded calculations. Thus the safety analysis of the node (e.g. voltage stability margin) can be based on nose curve from Thévenin's equivalent.

The impact of the assumed value of series impedance angle on accuracy of approximation the Thévenin's model parameters was also investigated. The test model consists of three nodes, lines between them and two voltage sources connected to transmission nodes through transformers. Two nodes are transmission nodes (1, 3) and one is receiver node (2). Significant RL loads (resistance in series with inductance) were connected to the nodes (1, 3). The volume of load has been increased until voltage in node reached the level of 0.9 of nominal. Obtained limits of series angle variation for the full model test are shown in Table 1.

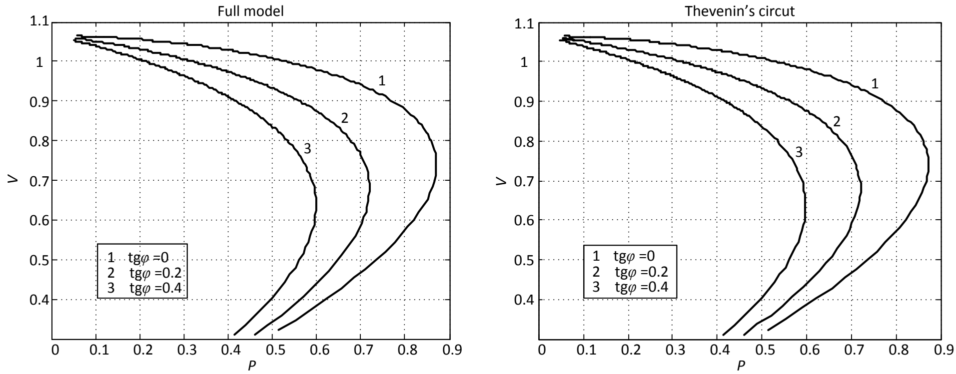

Fig. 3. Nose curves from the full model and Thevenin's circuit

Table 1. Value of system angle at the receiving node

System angle in node 2		
Load angle	Load location	
	Node 1	Node 3
[deg]	[deg]	[deg]
0	75.3	76.5
90	87.3	87.2

Specified values of the angle were applied in $\mathrm{d}S/\mathrm{d}V$ algorithm. Then curves obtained from calculation of series system impedance value and voltage source were plotted. The curves are shown in Fig. 4. The correct values of system impedance Zs and voltage source E are 0.01252 + j0.3136 and 1.067, respectively. Impedance angle calculated from full model series system is 87.7°. When the Z_S/Z_L ratio is low, the errors can be significant. The errors can reach a value up to 28%. However, when load admittance is low, margin of voltage stability is high, so the error can be tolerated. Coming closer to the stability limit errors decrease nearly to zero. So the worse situation implies the more accurate determination of Thevenin's model parameters. Fig.4 also shows that for load impedance angle value higher than the correct one the calculated value of system impedance is greater. Overestimated system impedance means a greater voltage stability margin.

Thus a better solution is revaluation of system impedance angle because this makes the algorithm more sensitive. The curves in Fig. 4 show that applying angle 3 degrees higher or lower than current value cause similar errors.

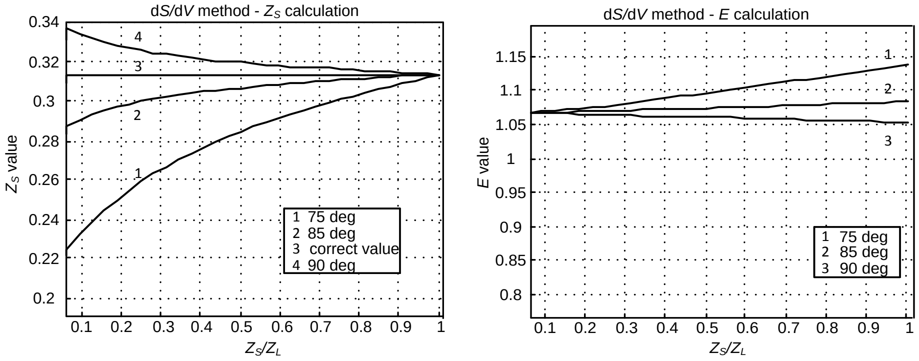

Fig. 4. Calculation of E and Z_s values

The case of Thevenin's model parameters determination for the working point located in the middle of the stability margin (85 degrees entered) is shown in Fig. 5. The curves show that calculation errors do not exceed 10%.

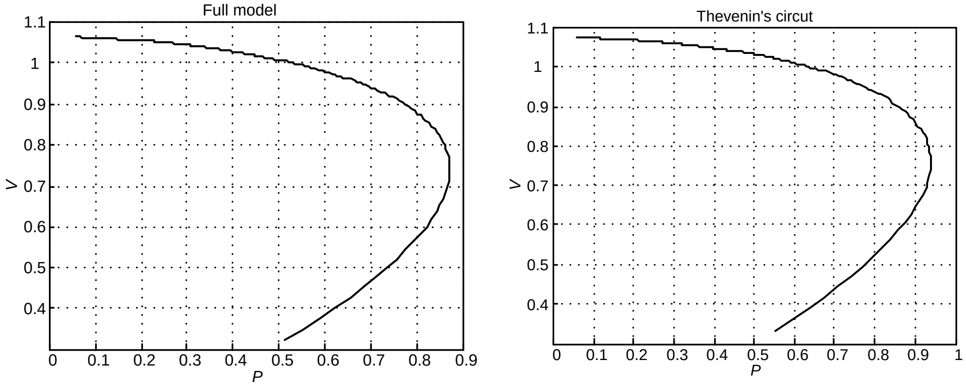

Fig. 5. Nose curves from full model and Thevenin's circuit

4. CONCLUSIONS

Thevenin's equivalent can be a useful tool for determining of local voltage stability margin. Method which uses only local measurement for calculation of model parameters can be applied in protective and preventive devices. Calculation of series system impedance can also be a measure of local voltage stability margin. The limit of stability occurs when Z_S/Z_L=1 or Y^* Z_S =1 [3]. Value of load admittance Y can be measured and the value of Z_S can be determined by using one of two methods presented.

When wide area measurement will be easily available then the combination of both presented methods will be the best solution to the Thevenin's model parameters determination. This will eliminate the disadvantages of both methods. When power system configuration data will be available the system impedance value and angle will be able to determine by use of the full model method. If these data are not available then the Thevenin's model will be updated by the dS/dV method.

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OKREŚLANIE MODELU EKWIWALENTU THEVENINA W WĘŹLE ODBIORCZYM

Artykuł przedstawia właściwości modelu Thevenina. Uproszczony model reprezentujący aktualną konfigurację systemu może mieć zastosowanie w automatyce zabezpieczeniowej oraz prewencyjnej montowanej w punkcie odbiorczym. Model Thevenina może być tworzony przy użyciu dwóch metod: korzystając z informacji o pełnej konfiguracji systemu oraz z algorytmu wyliczającego parametry modelu na podstawie pomiarów lokalnych fazorów napięć i prądów. Korzystając z pomiarów lokalnych, wyliczana jest pochodna mocy pozornej po napięciu dS/dV. Przeprowadzono testy dokładności algorytmu dS/dV w zależności od założonego kąta impedancji systemowej. Ważnym problemem, jaki jest poruszony w artykule jest aktualizacja modelu zgodnie ze zmieniającą się konfiguracją systemu elektroenergetycznego. Zmiany mogą być wywoływane stanami normalnej pracy jak i awariami występującymi w systemie. Przedstawiono wady i zalety stosowania obu metod.