The Influence of the Power Systems from the Neighboring Countries, on the Fault Currents in the Macedonian Power System

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Abstract – **In this paper is presented the influence of the each neighboring power system and all together on the value of the fault currents in the power system of the Republic of Macedonia. All 400 kV connection lines among power systems are taken into account. The mathematical models of the power system elements and methodology for calculation of three and one phase fault currents are shortly described. The power systems of the neighboring countries Serbia, Bulgaria and Greece are modelled with the Ward's equivalents which are adequately connected in the connection nodes of the power system of the Republic of Macedonia. A way for Ward's equivalent obtaining with rearranging the admittance matrix of the regional power system is explained. With application of the software package Neplan 5.3.5, calculations are performed for five cases and obtained results for three and one phase fault currents in important nodes of the power system of the Republic of Macedonia are given.**

Keywords – **Power system connections, Fault currents, Ward's equivalent.**

I. Introduction

The values of the fault currents in the power system nodes are very important data for choosing the electrical equipment and their performances. The circuit breakers, disconnectors, measuring current transformers and lighting protection bare conductors should be chosen according to the maximum fault current in the sub-transient period. Also, the fault current data are necessary for setting the protection devices and designing the grounding systems. The degree of safety, reliable and stable function of the power systems depends of the type and duration of the fault currents. Liberalization of the electricity market enable the consumers to provide the electricity not only from the power plants in the Republic of Macedonia but from the power systems of the neighboring countries and wider. For these reasons to obtain the better transfer capacities the power system of the Republic of Macedonia (PSM) is connected with 400 kV lines with the power systems of the neighboring countries. With Serbia there is line between TS Skopje 5 – TS Kosovo B, with Bulgaria exist line between TS Shtip – TS Chervena Mogila and with Greece there are two connection lines: TS Bitola 2 – TS Lerin and TS Dubrovo – TS Solun. The new 400 kV lines which are planned in the future are with Serbia TS Shtip – TS Nish and with Albania TS Bitola 2 – TS Ohrid – TS Elbasan [1]. The connections among power systems with 220 kV and 110 kV lines are not taken in the analysis because of small transfer capacities or because some of them are not in function.

The regional connections among the power systems of different countries increase the degree of safety, reliable and stable working of the each power system. On the other hand, these connections influence on the fault currents increasing in each of the power systems separately. That's just the point to take into account mutually connections among the power systems when fault currents analysis are performed.

With application of the software package Neplan 5.3.5 [2], calculation of three phase fault currents (3pfc) and one phase fault currents (1pfc) for five state cases are performed for the PSM. The power systems of the neighboring countries are modeled with Ward's equivalents obtained on the data base of the regional South-East Europe power systems [3]. All data for the power systems are taken for the state in year 2012 [1].

II. Power System Elements Modelling and Method for Fault Currents Calculation

In the Macedonian power system there are overhead lines with total length of 507 km for 400 kV, 103 km for 220 kV and 1480 km for 110 kV voltage level. The total number of transformer stations is five for 400/110 kV/kV, two for 220/110 kV/kV and sixty for 110/x kV/kV voltage levels [1]. One line diagram of the Macedonian power system is shown on Fig. 1 (state in 2012). All 400, 220 and 110 kV transmission lines and all 400/110, 220/110 and 110/x kV/kV transformer stations are taken into account in the power system model for fault current calculation. The overhead transmission lines are modelled with "π"-equivalent scheme for the positive and negative-sequence systems with serial impedance $\underline{Z}_v = (R_v + jX_v)$ and shunt jB_v branches. The impedance for the zero-sequence system is greater than positive-sequence system and depends of earth conductivity, disposition of phase conductors and presence (and number) of lighting protection conductors. These impedances are obtained by multiplying the values of positive-sequence system impedances with proper coefficients [4]. The transformers are modelled with "G"-equivalent scheme for the positive and negative-sequence systems with impedance serial branch $\underline{Z}_t = (R_t + jX_t)$ and shunt admittances $\underline{Y}_t = (G_t - jB_t)$.

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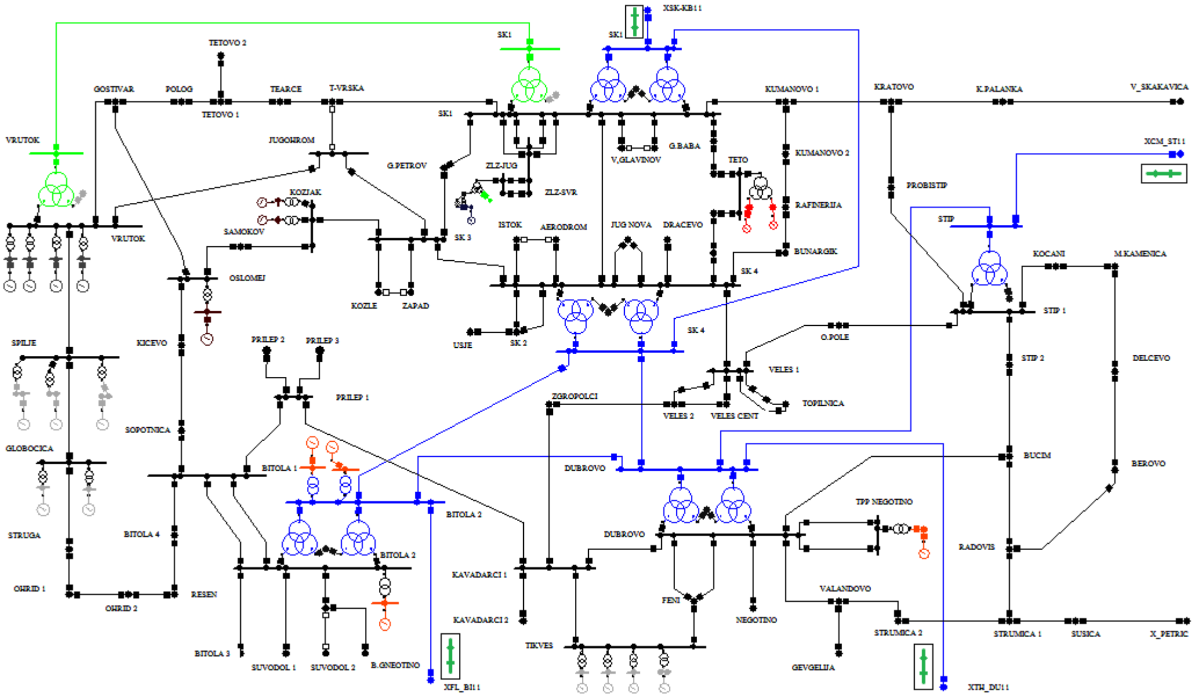

Fig. 1. One line diagram of the power system of the Republic of Macedonia (state in year 2012).

The equivalent scheme and impedance value for the zero-sequence system depends of the transformer windings connection, grounding of the winding neutral point(s) (if they exist) and transformer construction (3, 4 or 5 iron cores) [4]. During the fault duration, the synchronous generators change their reactance. In the sub-transient period the positive-sequence reactance is $X_+^{''}$, negative-sequence reactance is $X_- \approx X_+^{''}$. The zero-sequence reactance depends of the generator neutral point treatment [4].

Calculations of fault currents are performed according to the IEC 60909 standard proposed by the IEC technical committee 73 [5]. This standard consists of a base document and five additional parts in which are defined all necessary steps for fault currents calculation in low and high voltage three phase power systems with rated frequency of 50 or 60 Hz. With this standard is established a general and precise procedure which gives the results with acceptable accuracy. The calculating method in the standard is based on theory for calculating the equivalent voltage generator and equivalent impedance on the fault point for positive, negative and zero-sequence circuits. Main assumptions which are taken into account during the calculations are:

− all shunt admittances and loads which haven't rotation parts (except one for the zero-sequence) are neglected;
− voltage of the equivalent voltage generator during the fault duration is with the value of 1,1·U_n (where U_n is rated voltage on the fault point);
− topology structure of the power system is that one which has maximum fault current in the fault point;
− maximum 3pfc and 1pfc are calculated only for the sub-transient period;
− voltage and power regulators are not activated.

III. Obtaining of Ward's Equivalents

The Ward's equivalents of the power systems of the neighboring countries are obtained according to the data for the regional transmission network of the South-East Europe shown on Fig 2. These models are taken from the Department of strategic planning and power system analysis in AD MEPSO - Skopje.

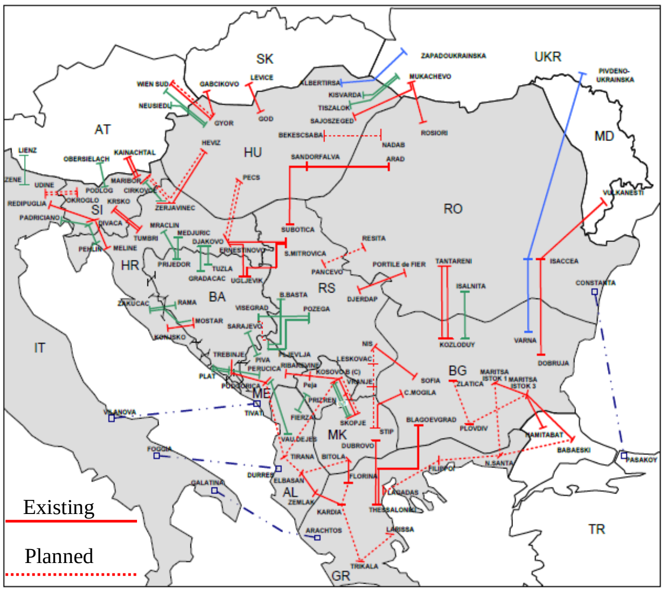

Fig 2. Regional transmission lines in South-East Europe.

The final models of the Ward's equivalents are consisted of the ending nodes of transmission lines which connect the neighboring power systems. These nodes are signed as terminal nodes. All terminal nodes are connected with equivalent transmission lines and in each node exists an equivalent generator. The connecting transmission lines among PSM and neighboring countries, equivalent transmission lines among terminal nodes and equivalent generators of the Ward's equivalents are shown on Fig 3.

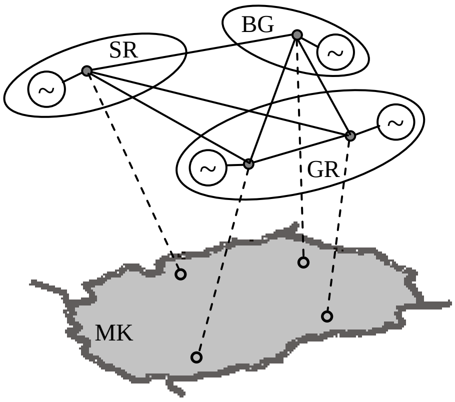

Fig. 3. Network model for fault currents calculation in the PSM.

The parameters of the equivalent transmission lines and generators are obtaining with simple procedure for regional power system admittance matrix $\mathbf{Y}^{externo}$ rearrangement. This matrix is concerned on external (neighboring) power systems which influence should be taken into account.

If neighboring power systems have n nodes and if the procedure for obtaining Ward's equivalent results with nt terminal nodes, than parameters for equivalent transmission lines and generators are implemented in sub-matrix signed as $\mathbf{Y}^{ward}$. These parameters are obtaining through the elements of the $\mathbf{Y}^{externo}$ matrix [6]. At first, the elements of $\mathbf{Y}^{externo}$ which correspond to terminal nodes nt should be displaced in the last rows and columns with scripts from $(n-nt+1)$ to n and group in sub-matrix **W**, as it is shown on Fig. 4.

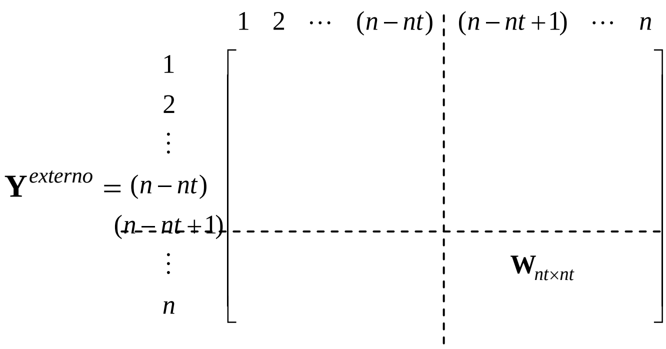

Fig. 4. Admittance matrix structure for the neighboring power systems.

It is necessary to update the values of the $\mathbf{Y}^{externo}$ matrix applying Eq. 1:

$$Y_{jk} = Y_{jk} - \frac{Y_{ji}}{Y_{ii}} \cdot Y_{ik}\,; \qquad (1)$$

$$i = 1,\ldots(n-nt);\; j=(i+1),\ldots n;\; k=(i+1),\ldots n.$$

Using the elements from sub-matrix **W** and applying Eqs. 2, the elements of sub-matrix $\mathbf{Y}^{ward}$ can be calculated as:

$$\text{for } i = 1,\ldots nt;\; j = 1,\ldots nt \;\Rightarrow$$

$$pom = \sum W_{ij}\,; \quad i \neq j\,;\; Y_{ij}^{ward} = -W_{ij}\,; \quad i \neq j$$

$$\text{and } Y_{ij}^{ward} = W_{ij} + pom\,; \quad i = j. \qquad (2)$$

For the Ward's equivalents, the impedances of the equivalent generators are obtained by the reciprocal values of the diagonal elements and the serial impedances of the equivalent transmission lines are obtained by the reciprocal values of the off-diagonal elements of $\mathbf{Y}^{ward}$.

IV. Fault Current Calculation in the PSM

The purpose of this paper is to show the influence of the 400 kV connections with neighboring power systems (all together and separately) on the increasing of the fault currents in the PSM. Therefore, applying the software package Neplan 5.3.5, calculations of 3pfc and 1pfc for the following five state cases are performed for the PSM [7]:

1. The system works with all 400 kV connections to the power systems of the neighboring countries (results in Table I).
2. The system works with connection only with the power system of the Republic of Serbia (results in Table II).
3. The system works with connection only with the power system of the Republic of Bulgaria (results in Table II).
4. The system works with connection only with the power system of the Greece (results in Table II).
5. The system works independently (without any connection with other power system, results in Tables I and II).

The fault currents comparison is given in Tables I and II.

Table I
Fault currents comparison between case 1 and case 5.

Node	U [kV]	Case 5-alone		Case 1-all		Δ_{pfc}	
		3pfc [kA]	1pfc [kA]	3pfc [kA]	1pfc [kA]	3pfc [%]	1pfc [%]
BITOLA2	400	6,6	7,8	18,5	18,2	**180,0**	**134,0**
DUBRVO	400	6,1	6,8	16,7	15,3	**176,2**	**123,1**
SKOPJE1	400	5,6	6,4	13,2	14,2	**135,6**	**121,9**
SK 4	400	6,2	7,2	14,4	14,6	**133,1**	**104,5**
STIP	400	4,8	4,9	11,7	9,9	**145,5**	**99,4**
BITOLA2	110	16,0	20,5	23,5	29,0	46,8	41,5
DUBRVO	110	16,5	19,8	25,3	28,5	53,1	43,9
SKOPJE1	110	17,6	21,7	27,2	32,4	54,7	49,2
SK 4	110	17,7	21,7	27,6	32,0	55,5	47,4
STIP 1	110	10,3	11,7	14,2	15,2	38,0	30,3
TIKVES	110	11,1	11,1	13,9	12,9	24,9	16,5
TETO	110	15,8	16,0	21,0	19,7	33,0	22,9

TABLE II
FAULT CURRENTS COMPARISON AMONG CASE 5, CASE 2, CASE 3 AND CASE 4.

Node	U [kV]	Case 5-alone		Case 2-Serbia		Case 3-Bulgaria		Case 4-Greece		Δ_{2-5}		Δ_{3-5}		Δ_{4-5}	
		3pfc [kA]	1pfc [kA]	3pfc [kA]	1pfc [kA]	3pfc [kA]	1pfc [kA]	3pfc [kA]	1pfc [kA]	3pfc [%]	1pfc [%]	3pfc [%]	1pfc [%]	3pfc [%]	1pfc [%]
BITOLA2	400	6,6	7,8	8,3	9,7	8,1	9,3	16,4	16,6	25,8	24,3	23,1	18,7	**148,1**	**113,5**
DUBRVO	400	6,1	6,8	7,8	8,6	8,9	9,3	12,9	12,5	29,1	25,6	46,8	36,6	**112,4**	**82,0**
SKOPJE1	400	5,6	6,4	10,1	11,9	6,7	7,3	8,4	8,7	**79,5**	**86,7**	19,9	15,1	49,8	35,6
SK 4	400	6,2	7,2	9,9	11,4	7,7	8,5	10,1	10,5	60,2	59,2	24,2	18,7	64,0	46,7
STIP	400	4,8	4,9	5,8	5,8	8,3	7,8	7,9	7,1	20,8	16,6	**74,8**	**58,3**	65,6	43,1
BITOLA2	110	16,0	20,5	17,9	23,0	17,7	22,5	22,6	28,0	11,8	12,3	10,7	9,7	41,6	36,8
DUBRVO	110	16,5	19,8	18,9	22,6	20,1	23,4	23,1	26,3	14,3	13,9	21,5	18,1	39,7	32,8
SKOPJE1	110	17,6	21,7	23,6	29,3	19,8	24,0	22,5	26,7	34,4	35,2	12,6	10,7	28,1	23,2
SK 4	110	17,7	21,7	23,3	28,4	20,2	24,3	23,3	27,3	31,3	30,8	14,1	11,8	31,3	25,5
STIP1	110	10,3	11,7	11,4	12,8	12,6	13,8	12,8	13,7	10,3	9,3	22,1	18,2	24,2	18,7
TIKVES	110	11,1	11,1	12,0	11,8	12,3	11,9	13,2	12,5	7,9	6,3	11,2	7,7	19,4	13,0
TETO	110	15,8	16,0	19,0	18,6	17,2	17,0	18,8	18,1	20,7	16,3	9,1	6,3	19,2	13,0

The fault currents when the PSM works without (case 5) and with all connections with neighboring countries (case 1) and percentage of 3pfc and 1pfc increasing, signed as Δ_{pfc} are shown for five 400 kV nodes and seven 110 kV nodes in which the increasing are the biggest (Table I). It is obvious that in 400 kV nodes (on which voltage level are connections with neighboring countries) the increasing of the fault currents are bigger, than in the nodes with lower voltage levels, dipper in the PSM. The increasing of the fault currents in the PSM, when exist connection with only one of the neighboring countries power systems are shown in the same nodes as in case 1. The percentage of fault currents increasing when PSM is connected only with the power system of: Serbia is signed as $\Delta_{2\text{-}5}$, Bulgaria as $\Delta_{3\text{-}5}$ and Greece as $\Delta_{4\text{-}5}$. Comparing the results in Table II we can conclude that the biggest influences of the fault currents increasing are in the nodes where exist 400 kV transmission lines which connect PSM and neighboring countries power systems.

V. CONCLUSION

Knowing the values of the fault currents in the power system nodes is very important for choosing the equipment performances, relay protection setting, stability analysis, designing the grounding systems, etc. The connections with high voltage transmission lines among the neighboring countries power systems influence on the fault currents increasing in each of the systems separately. Because of the above mentioned reasons it is very important to take into account this influence and calculate correct fault currents. In this paper is shown a way how to calculate the influence of the neighboring countries power systems on the fault currents increasing in the power system of the Republic of Macedonia.

With real data for the power systems of the countries in South - East Europe obtained from [3] and software package [2], the fault currents in the nodes of the power system of the Republic of Macedonia are calculated. Five cases for different connections with neighboring countries are analyzed [7]. The results of obtained fault currents values and percentage of current increasing for each case are shown in proper tables. The obtained results are verified with their comparison with results presented in [1] which are obtained with software package PSS/E v.32.0.

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