*Trivent Publishing*
© The Authors, 2015
Available online at http://trivent-publishing.eu/

*Engineering and Industry* Series
Volume *Deregulated Electricity Market Issues in South Eastern Europe*

# Modelling the SSSC Device in the Power Flow Problem as Power Injections Regulated According to First Order Sensitivity

Gorazd Bone and Rafael Mihalič

***Abstract***
*In this paper we present a possibility of modeling the Static Synchronous Series Compensator (SSSC) in the load flow problem as power injections at the nodes of the line into which it is inserted. The power injections representing the SSSC are used as inputs in a power flow calculation. Upon solving the power flow calculation, without an SSSC device, a mismatch vector, consisting of SSSC requirements is obtained. The power injections representing the SSSC device are then updated so as to minimize the mismatch vector in accordance with first order sensitivity and the load flow calculation is restarted with newly obtained injections. Convergence of this procedure is obtained when the mismatch vector after a power flow calculation is sufficiently small.*

***Keywords***
*SSSC modelling, power flow, load flow, Newton's method, sensitivity analysis, power injection modeling*

## I. INTRODUCTION

In this paper we try to develop a method to model the SSSC device with power injections which are regulated according to Newton's method. The possibility of modelling the SSSC device with power injections has been known for some time in the scientific community; however the authors normally use some difference method to update the injections [5].

The main advantage of this type of modelling in our opinion is the fact that power injections are inputs to the power flow problem, thus one can model the SSSC device without actually changing the power flow program. Since it is usually the case that engineers would rather use available software to do load flow calculations than to program a load flow program on their own this approach might be a useful tool in enabling the modelling of SSSC in load flow calculation. The SSSC modelling described here is established for a device that controls the power at the receiving bus at the line of its insertion.

## II. TECHNICAL WORK PREPARATION

Let us consider an SSSC which should be modelled with power injections at nodes of its insertion, which are changed in accordance to Newton's method. The newton's method works in the following way: firstly a function is obtained which has the property of being equal to zero when the objectives of the problem are met. In the conventional load flow calculations these Newtonian objectives are power injections [1] or current injections [2] at each node. This function is generally a nonlinear one and the analytical expression for its zero is not known. The Newton's method uses first order sensitivity to try and numerically find the zero which will provide the solution to the problem at hand. Because the mentioned function is zeroed it is usually denoted as the criteria function.

In this part it is first explained how this cost function is obtained and why it is sufficient to model the SSSC device. Further the way of acquiring the first order sensitivity, which is necessary for the Newton's method, is discussed.

In the case of an SSSC the cost function in question is formulated *in the following way*. Firstly, it should be noted that each SSSC device contributes four unknowns; the active and reactive power injections at both nodes of insertion. This means a vector function needs to be procured (the element of which are mutually independent functions) whose dimension is the number of SSSC devices multiplied by four (for a system to be determined the number of variables must equal the number of independent equations).

The first two equations are derived from the following two conditions; firstly the SSSC device *must not produce nor consume active power during its operation* (any possible losses are modelled with a series resistance added to the line's impedance), secondly *the control objective needs* to be met. In this work an SSSC controlling active power flows over the branch of its insertion is considered. If the SSSC device is modelled conventionally these two are the only conditions present [7,8], the power flow problem is then



DOI: 10.22618/TP.EI.20151.192013

increased by two equations and two unknowns and the Jacobian is expanded.

The other two equations that each SSSC device contributes are derived from the fact that each SSSC operates as a voltage source with series impedance (by first representing this voltage source as a Norton equivalent current source and then demanding the corresponding injected currents match).

The development of the power injection model will be shown next. The SSSC device can be modelled as a voltage source in series with impedance (the impedance of the SSSC):

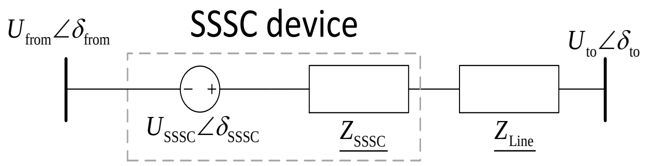


Fig. 1. The SSSC device as normally modelled.

This directly simplifies into:

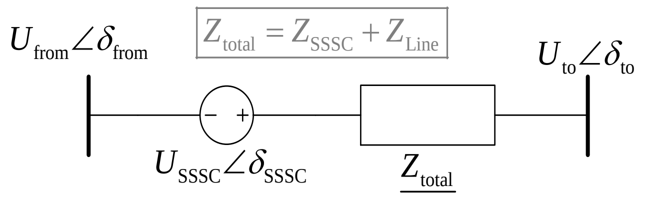


Fig. 2. SSSC equivalent branch, summing impedances

Taking the Norton equivalent of figure 2 we obtain:

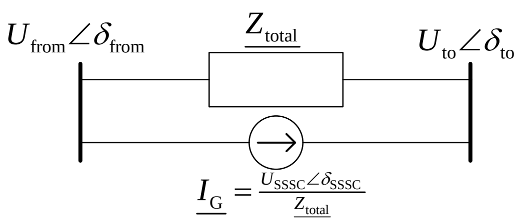


Fig. 3. SSSC equivalent branch, Norton equivalent

The latter can be restated in terms of power injections in the following way:

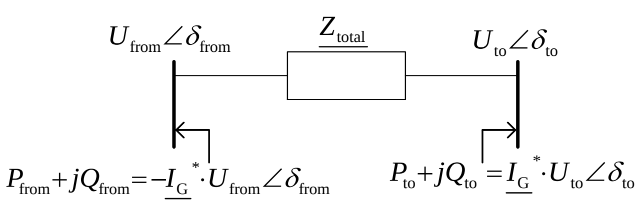


Fig. 4. SSSC equivalent nodal power injections at ends of line of insertion

From the above circuits the other two conditions of the criteria function for modeling an SSSC can be established. It should be assured that the SSSC device is modelled as a voltage source. This condition will be met, according to figure 3, if it can be modelled as an equivalent current source, meaning the injected currents at both nodes need to be equal. This condition is established with accordance to figure 4. By equating *both real and imaginary parts of the injected current at the "from" bus to that of the "to" bus*, two equations are obtained which, with the addition of two previously mentioned make up for a full definition of the SSSC model.

It is clear, that once the nonlinear function comprised in the way explained (zero net active power, the regulated variable being equal to set condition, real and imaginary parts of current injections need to match), the power injections will model an SSSC device. The parameters of the SSSC device, $U_{SSSC}$ and $\delta_{SSSC}$, can then be calculated from the injected powers and the voltages and angles at the busses of each SSSC device.

The equations for the criteria function will now be derived. Firstly the regulating condition will be stated. We chose to regulate active power flow over the line of SSSC's insertion. We therefore subtract the specified power flow ($P_{spec}$ ) from the actual power flow on that line. The difference between the two needs to equal zero. The active power transfer is (figure 2):

$$P_{ij} = \mathrm{Re}\left\{ \left( \frac{U_{from}\angle\delta_{from} + U_{SSSC}\angle\delta_{SSSC} - U_{to}\angle\delta_{to}}{\underline{Z}_{total}} \right)^{*} \cdot U_{to}\angle\delta_{to} \right\} \tag{1}$$

In the last equation the $U_{SSSC}$ and the $\delta_{SSSC}$ need to be eliminated in terms of input variables $P_{from}$, $Q_{from}$, $P_{to}$, $Q_{to}$ and in terms of variables that are already present in the load flow program, $U_{from}$, $\delta_{from}$, $U_{to}$, $\delta_{to}$. This is done by first noting the use of the Norton equivalent,

$$U_{SSSC}\angle\delta_{SSSC} = \underline{Z}_{total} \cdot I_G \tag{2}$$

And then noting the value of the Norton equivalent can be expressed in terms of nodal input powers, voltages and their angles as:

$$\underline{I}_G = \left( \frac{P_{to} + jQ_{to}}{U_{to}\angle\delta_{to}} \right)^{*} \tag{3}$$

We insert (3) into (2), the result of that into (1), and define;

$$Z_{total} = Z\angle\delta_z \tag{4}$$

From thus derived expression for $P_{ij}$ we subtract $P_{spec}$ and obtain:

$$\frac{\left(P_{to} - P_{spec}\right)\cdot Z - U_{to}^{2}\cdot\cos\left(\delta_z\right)}{Z} + \frac{U_{to}\cdot U_{from}\cdot\cos\left(\delta_{to} - \delta_{from} + \delta_z\right)}{Z} \tag{5}$$

When equation (5) equals zero the regulation condition will be met.

The zero net active power condition is defined from figure 2. The active power of the voltage source that represents SSSC can be expressed as follows:

$$dP_{\mathrm{e}} = \mathrm{Re}\left\{\left(\frac{U_{\mathrm{from}}\angle\delta_{\mathrm{from}}+U_{\mathrm{SSSC}}\angle\delta_{\mathrm{SSSC}}-U_{\mathrm{to}}\angle\delta_{\mathrm{to}}}{\underline{Z}_{\mathrm{total}}}\right)^{*}\cdot U_{\mathrm{SSSC}}\angle\delta_{\mathrm{SSSC}}\right\} \quad (6)$$

After a similar streak of operations as before we obtain:

$$\begin{aligned}&\left(\left(P_{\mathrm{to}}^{2}+Q_{\mathrm{to}}^{2}\right)\cdot Z\cdot\cos\delta_{\mathrm{z}}+U_{\mathrm{to}}\left(-P_{\mathrm{to}}U_{\mathrm{to}}\cdot\cos\left(2\cdot\delta_{\mathrm{z}}\right)\right.\right.\\&+P_{\mathrm{to}}U_{\mathrm{from}}\cdot\cos\left(\delta_{\mathrm{to}}-\delta_{\mathrm{from}}+2\delta_{\mathrm{z}}\right)-Q_{\mathrm{to}}U_{\mathrm{to}}\cdot\sin\left(2\cdot\delta_{\mathrm{z}}\right)\\&\left.\left.+Q_{\mathrm{to}}U_{\mathrm{from}}\cdot\sin\left(\delta_{\mathrm{to}}-\delta_{\mathrm{from}}+2\delta_{\mathrm{z}}\right)\right)\right)\cdot\frac{1}{U_{\mathrm{to}}^{2}}=dP_{\mathrm{e}}\end{aligned} \quad (7)$$

When the above equation equals zero the net active power will be zero.

The final two conditions define the power injections as stemming from the same current source as in figure 3. If the current $I_{\mathrm{G}}$ is expressed in terms of the "from" bus we have:

$$\underline{I}_{\mathrm{G}}=\left(\frac{P_{\mathrm{from}}+jQ_{\mathrm{from}}}{U_{\mathrm{from}}\angle\delta_{\mathrm{from}}}\right)^{*}, \quad (8)$$

if it is expressed in terms of the "to" bus, we get (3). Both the real and the imaginary part of (8) are subtracted from (3) to obtain the equations:

$$\begin{aligned}&P_{\mathrm{from}}\cdot U_{\mathrm{to}}\cdot\cos\left(\delta_{\mathrm{to}}\right)+P_{\mathrm{to}}\cdot U_{\mathrm{from}}\cdot\cos\left(\delta_{\mathrm{from}}\right)\\&-Q_{\mathrm{from}}\cdot U_{\mathrm{to}}\cdot\sin\left(\delta_{\mathrm{to}}\right)-Q_{\mathrm{to}}\cdot U_{\mathrm{from}}\cdot\sin\left(\delta_{\mathrm{from}}\right)\end{aligned} \quad (9)$$

and

$$\begin{aligned}&Q_{\mathrm{from}}\cdot U_{\mathrm{to}}\cdot\cos\left(\delta_{\mathrm{to}}\right)+Q_{\mathrm{to}}\cdot U_{\mathrm{from}}\cdot\cos\left(\delta_{\mathrm{from}}\right)\\&+P_{\mathrm{from}}\cdot U_{\mathrm{to}}\cdot\sin\left(\delta_{\mathrm{to}}\right)+P_{\mathrm{to}}\cdot U_{\mathrm{from}}\cdot\sin\left(\delta_{\mathrm{from}}\right),\end{aligned} \quad (10)$$

for the real and imaginary parts respectively. When the vector function comprised of equations (5) , (7) , (9) and (10) equals zero the power injections at the lines of SSSC' insertion will act as the SSSC device modelled.

For several SSSC devices the vector function is concatenated so that it embodies the derived conditions for all the devices. A vector with the dimensions equal to four times the number of SSSC devices is thus obtained and when this vector equals zero the problem of device control is met. The function for each SSSC device is as follows:

$$\mathbf{H}_{\mathrm{SSSC\_k}}=\begin{bmatrix}(5)\\(7)\\(9)\\(10)\end{bmatrix}, \quad ,(11)$$

where the numbers indicate the numbers of equations present. The k index passes over each SSSC device, from 1 to N, where N is the number of SSSC devices. The complete function for the SSSC modelling is obtained as:

$$\mathbf{H}_{\mathrm{SSSC\_total}}=\begin{bmatrix}\mathbf{H}_{\mathrm{SSSC\_1}}\\\mathbf{H}_{\mathrm{SSSC\_2}}\\\vdots\\\mathbf{H}_{\mathrm{SSSC\_N}}\end{bmatrix} \quad (12)$$

*Next the mechanism for zero finding according to Newton's method will be discussed*. For sake of brevity the equations that directly follow will not be stated. Their derivation can easily be done by using a software package capable of handling symbolic computations, which is the approach we used.

The first order sensitivity of the vector function discussed needs to be derived w.r.t. the control parameters; the power injection of the SSSC devices. The derivation must not be partial, but total. However, since the function in (12) is not just dependent upon the injected powers controlled but also upon the variables of the load flow problem (nodal voltages and angles at nodes of insertion) the total derivative must be obtained indirectly by using partial derivatives. Stated in terms of an equation:

$$\frac{d\mathbf{H}_{\mathrm{SSSC\_total}}}{d\mathbf{U}}=\frac{\partial\mathbf{H}_{\mathrm{SSSC\_total}}}{\partial\mathbf{U}}+\frac{\partial\mathbf{H}_{\mathrm{SSSC\_total}}}{\partial\mathbf{X}}\cdot\frac{d\mathbf{X}}{d\mathbf{U}} \quad (13)$$

In the above equations the vector **U** is a column vector that contains the inputs of the load flow being controlled (the nodal injections at nodes of SSSC insertion) as follows:

$$\begin{aligned}\mathbf{U}=\left[P_{\text{from-1}},Q_{\text{from-1}},P_{\text{to-1}},Q_{\text{to-1}},\ldots\right.\\\left.\ldots,P_{\text{from-N}},Q_{\text{from-N}},P_{\text{to-N}},Q_{\text{to-N}}\right]^{\mathrm{T}},\end{aligned}$$

where N is the number of SSSC devices.

The vector **X** contains all the variables of the load flow (angles and voltages for power mismatch formulation). The partial derivatives w.r.t. to **U** are simple to obtain and will not be discussed. The partial derivatives w.r.t. **X** are also simple to obtain, note here, that the partial derivatives w.r.t the variables which are not present in the function $\mathbf{H}_{\mathrm{SSSC\_total}}$ are simply zero. And so, the total derivative of **X** w.r.t. **U** is the one which we will address further.

The total derivative is defined by the constraint that the load flow problem poses. The load flow problem can be visualized as a vector function of the variables **X (**these being voltages and angles for power mismatch based load flow), of the parameters being changed **U** (these are the nodal injections of power at the nodes of SSSC insertions) and of the parameters that remain fixed **P** (this last one being all the other power injections and the line parameters or any other parameters present in the load flow). The load flow is defined by the constraint:

$$\mathbf{G}(\mathbf{X},\mathbf{U},\mathbf{P}) = \mathbf{0} \tag{14}$$

The vector function **G** is, if we formulate the power flow problem in terms of power injections, the sum of nodal powers for each node; active and reactive for PQ and active alone for PV buses. Deriving equation (14) w.r.t. the control vector **U** we obtain:

$$\frac{d\mathbf{G}}{d\mathbf{U}} = \frac{d}{d\mathbf{U}}\mathbf{0} = \mathbf{0} = \frac{\partial \mathbf{G}}{\partial \mathbf{U}} + \frac{\partial \mathbf{G}}{\partial \mathbf{X}} \cdot \frac{d\mathbf{X}}{d\mathbf{U}}, \tag{15}$$

which implies:

$$\frac{d\mathbf{X}}{d\mathbf{U}} = -\left(\frac{\partial \mathbf{G}}{\partial \mathbf{X}}\right)^{-1} \cdot \frac{\partial \mathbf{G}}{\partial \mathbf{U}} \tag{16}$$

The last identity is inserted into (13) to obtain the sensitivity:

$$\frac{d\mathbf{H}_{\text{SSSC\_total}}}{d\mathbf{U}} = \frac{\partial \mathbf{H}_{\text{SSSC\_total}}}{\partial \mathbf{U}} - \frac{\partial \mathbf{H}_{\text{SSSC\_total}}}{\partial \mathbf{X}} \cdot \left(\frac{\partial \mathbf{G}}{\partial \mathbf{X}}\right)^{-1} \cdot \frac{\partial \mathbf{G}}{\partial \mathbf{U}} \tag{17}$$

A similar explanation of how to calculate first order sensitivity of a nonlinear cost function in the load flow problem may be found in [3].

In (17) the two more complex parts of expression are the partial derivatives of the cost function w.r.t. the vectors U and X. We believe the best way to derive these two is by using a mathematical software capable of symbolic derivation. By doing so the possibility of having an erroneous expression is averted. The other two matrices present are then the partial derivative of the load flow condition **G** w.r.t. the variables' vector **X** and the partial derivative of **G** w.r.t input vector **U**. The first of the two mentioned is the Jacobian matrix of the load flow problem, the second is a matrix whose number of rows is the same to the number of rows of the Jacobian matrix, while the number of its columns is equal to the number of input parameters in the SSSC modelling, that being equal to four times the number of SSSC devices. The matrix that represents the partial derivative of **G** w.r.t. **U** is made up of columns of which each has one at the spot pertaining to the input of the SSSC devices modelled and zeroes elsewhere.

With the criteria function along with its first order sensitivity derived, we can carry out the Newtonian calculation of the zero which will lead to the solution in the SSSC modelling problem. The process is as follows:

1.) After the first load flow calculation we calculate the cost function $\mathbf{H}_{\text{SSSC\_total}}$ from equation (12) and check if its second norm is lower than a predetermined tolerance.

2.) If it is not, the sensitivity is calculated from equation (17). The change in the injected powers is then calculated as:

$$\Delta\mathbf{U} = -\left(\frac{d\mathbf{H}_{\text{SSSC\_total}}}{d\mathbf{U}}\right)^{-1} \cdot \mathbf{H}_{\text{SSSC\_total}} \tag{18}$$

3.) The injected powers need then to be superimposed by the amount found from (18). The load flow calculation is then repeated with the new power injections taken as parameters.

4.) The cost function $\mathbf{H}_{\text{SSSC\_total}}$ is calculated from equation (12). Its second norm is compared to a predetermined tolerance. If the norm is lower, the modelling has converged, if it is not, the process returns to step two.

Somewhere along the abovementioned steps one might wish to include a maximum iteration counter in case the process does not converge (according to our experience non-convergence may occur) and/or a limitation exceeding check to see if an internal variable of some SSSC is being forced out of its limitations. We did not deal with limitation consideration, although that might be considered in the conventional way.

There is a detail that should also be discussed at this point. In the load flow solution provided by the steps listed above the line flow of the final load flow, when the cost function's second norm is lower than the tolerance, will generally *not be the same as the line flow specified for the SSSC device*. The reason is that the two lines are not the same, which can be seen by comparing figures 1 and 4. To obtain the line flow of figure 1 we need to superimpose the line flow from the final load flow solution to the line flow contributed by the parallel, Norton equivalent line. The injected SSSC power must therefore be added to the calculated line flow at both nodes on the SSSC's insertion. By doing so the line flow with the SSSC inserted is obtained. The solutions in terms of the SSSC's voltage and angle can be found from equations (3) and (2).

## III. References

The proposed algorithm was tested on the IEEE 57 bus system. Results obtained were compared to those presented in [4]. In it the authors develop a current injection model of the SSSC device and compare it to the series voltage injection model as described in [8]. Although there are several cases of comparison provided in [4] we only look at one case in that paper. The reason for this is that only one of those cases pertains to the SSSC device being inserted into a line nested between PQ nodes.

In the studied case the active power over the line between nodes 24 and 25 is controlled. Several studies in which the regulated power flow was varied from 4 to 28 MW with a step of 1 MW have been carried out.

The results of the analysis found in [4] are presented in the figure below:

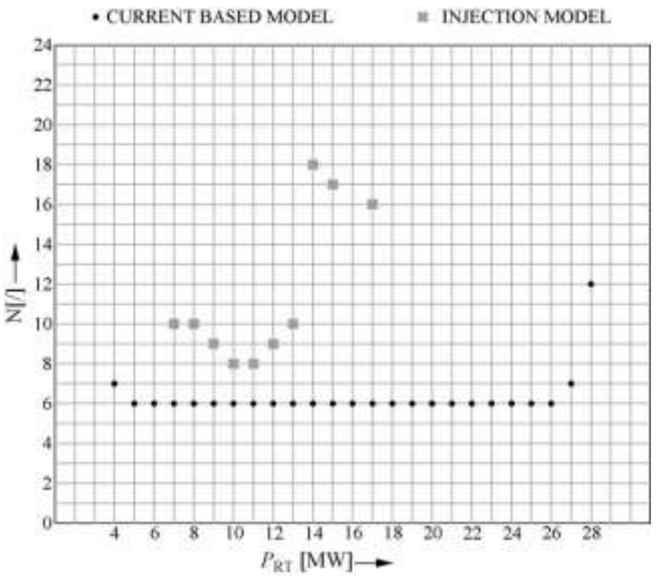


Fig. 5, Number of iterations, N, needed for the load flow calculation for various values of active power transfer as found in [4].

In Figure 5 it can be seen, that the current injection model provides for superior convergence as compared to the voltage injection model.

The table below contains the results of using the algorithm presented here. The line flow is in the left column and the number of load flow calculations carried out is next to it. The solutions, the values of injections at both nodes of the line, follow as indicated in the top row of the table.

For our study we set the impedance of the SSSC device to zero. Having an SSSC with nonzero impedance could however be easily accounted for by adding that impedance directly to the line of the SSSC's insertion in the raw data.

**Table 1: Results of calculation for IEEE 57 bus system with SSSC on line between nodes 24 and 25**

| $P$ [MW] | $N$ | $P_{from}$[MW] | $Q_{from}$[MW] | $P_{to}$[MW] | $Q_{to}$[MW] |
|---|---|---|---|---|---|
| 4 | 3 | 5.3434 | 1.5882 | -5.3434 | -0.9447 |
| 5 | 3 | 3.6035 | 1.0052 | -3.6035 | -0.6095 |
| 6 | 3 | 1.8616 | 0.4861 | -1.8616 | -0.3010 |
| 7 | 2 | 0.1177 | 0.0287 | -0.1177 | -0.0182 |
| 8 | 3 | -1.6281 | -0.3690 | 1.6281 | 0.2399 |
| 9 | 3 | -3.3758 | -0.7086 | 3.3758 | 0.4740 |
| 10 | 3 | -5.1252 | -0.9916 | 5.1252 | 0.6849 |
| 11 | 3 | -6.8762 | -1.2195 | 6.8762 | 0.8735 |
| 12 | 3 | -8.6290 | -1.3934 | 8.6290 | 1.0404 |
| 13 | 3 | -10.3833 | -1.5145 | 10.3833 | 1.1864 |
| 14 | 3 | -12.1392 | -1.5836 | 12.1392 | 1.3120 |
| 15 | 3 | -13.8967 | -1.6016 | 13.8967 | 1.4180 |
| 16 | 3 | -15.6556 | -1.5693 | 15.6556 | 1.5050 |
| 17 | 4 | -17.4159 | -1.4873 | 17.4159 | 1.5735 |
| 18 | 4 | -19.1776 | -1.3561 | 19.1776 | 1.6241 |
| 19 | 4 | -20.9407 | -1.1763 | 20.9407 | 1.6574 |
| 20 | 4 | -22.7052 | -0.9481 | 22.7052 | 1.6740 |
| 21 | 4 | -24.4709 | -0.6719 | 24.4709 | 1.6744 |
| 22 | 4 | -26.2379 | -0.3479 | 26.2379 | 1.6591 |
| 23 | 4 | -28.0062 | 0.0236 | 28.0062 | 1.6286 |
| 24 | 4 | -29.7756 | 0.4427 | 29.7756 | 1.5835 |
| 25 | 4 | -31.5463 | 0.9092 | 31.5463 | 1.5242 |
| 26 | 4 | -33.3181 | 1.4232 | 33.3181 | 1.4514 |
| 27 | 4 | -35.0911 | 1.9848 | 35.0911 | 1.3655 |
| 28 | 4 | -36.8652 | 2.5941 | 36.8652 | 1.2671 |

At this point it should be noted, that the iterations of the algorithm presented here need the entire power flow calculation to be carried out. Usually every power flow calculation would take 4 or 5 iterations.

In the table above the active powers at the sending and the receiving end have the same absolute value. The reason for this is that both, the line and the SSSC device, had no ohmic resistance (SSSC had zero impedance) and therefore the equivalent current source of figure 3 had no losses. When either the line or the SSSC devices have ohmic resistance the absolute values of the two will be different.

## IV. Conclusions and comments

It can be concluded that this type of modelling is a valid alternative to the conventional modelling type and might therefore be useful in some cases when the convergence is perhaps unattainable otherwise. Although we have not carried out a comprehensive study of convergence comparison it is usually the case that some algorithms may converge better than others. Such is the case with current based SSSC model which provides for better convergence as compared to the conventional SSSC model [4].

In this paper we have concentrated on the line flow at the receiving end. To regulate the line flow at the sending end the voltage and the angle of the voltage at the sending end must be used in equation(1). If one wants to model the power transfer at the point behind the SSSC ohmic losses of the device would have to be included.

The main difficulty of our method lies in correctly calculating the sensitivity of the cost function in eq. (17). This sensitivity calculation might however be done numerically, by perturbing one input at a time by a very small value, then running the load flow procedure and calculating the sensitivity coefficients of the cost function. Although the cost function would still need to be calculated the calculation of eq. (17) may be averted completely.

Since the SSSC device is modelled with power injections of real and reactive power at both buses of the line of insertion it is necessary that both nodes of the line are of PQ type since PQ is the type of node which will actually consider the calculated injections into the load flow.

## V. References

*Publications:*

[1] William. F. Tinney, Clifford E. Hart, " Power Flow Solution by Newton's Method" IEEE TRANSACTIONS ON POWER APPARATUS AND SYSTEMS VOL. PAS-86, NO. 11 NOVEMBER 1967

[2] Vander Menengoy da Costa, Nelson Martins, Josk Luiz R. Pereira "Developments in the Newton Raphson Power Flow Formulation Based on Current Injections",IEEE Transactions on Power Systems, Vol. 14, No. 4, November 1999

[3] A.G. Bakirtzis, "Sensitivity Computation for Power Flow Control in Electric Power Systems", Electric Power Systems research, 22 (1991) 77 – 84

[4] A. Vinkovic, R. Mihalic, "A current based model of the SSSC for Newton Raphson power flow", Electric Power Systems Research, 10/2008 ; 1806-1813

[5] Salah Kamel , Francisco Jurado , "Fast Decoupled Load Flow Analysis with SSSC Power Injection Model"; IEEJ TRANSACTIONS ON ELECTRICAL AND ELECTRONIC ENGINEERING IEEJ Trans 2014; 9: 370–374

[6] R. Benabid, M. Boudour, M.A. Abido, "Development of a new power injection model with embedded multi-control functions for static synchronous series compensator", IET Gener. Transm. Distrib., 2012, Vol. 6, Iss. 7, pp. 680–692

[7] Shagufta Khan, Suman Bhowmick,"A Novel Power Flow Model of a Static Synchronous Series Compensator (SSSC)", Power India International Conference (PIICON), 2014 6th IEEE

*Books:*

[8] Xiao-Ping Zhang , Christian Rehtanz , Bikash Pal , " Flexible AC Transmission Systems: Modelling and Control" Springer, 2005

*Internet links:*

[9] http://www.pserc.cornell.edu//matpower/

## VI. Biographies

**Gorazd Bone** received his B. Sc. Degree from the University of Ljubljana, Slovenia in 2011. Since then he has been a member of the Laboratory of Electrical Power Supply at the Faculty of Electrical Engineering, Ljubljana, Slovenia.

**Rafael Mihalic** received his Dipl. Eng., M.Sc. and Dr.Sc. degrees from the Faculty of Electrical Engineering, the University of Ljubljana, Ljubljana, Slovenia, in 1986, 1989 and 1993, respectively. In 1986 he became a Teaching Assistant in the Department of Power Systems and Devices and since 2005 he has been a full professor at the University of Ljubljana. Between 1988 and 1991, he was a member of the Siemens Power Transmission and Distribution Group, Erlangen, Germany. His areas of interest include system analysis and FACTS devices. He is a member of Cigre (Paris, France).