

Implementation of the parametric variation method in an EMTP program

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Abstract—The paper presents an algorithm for- and shows the implementation of a method to perform parametric variation studies using electromagnetic transients programs applied to an offshore wind farm. Those kind of studies are used to investigate the sensitivity of a given phenomena to variation of parameters in an electric system. The proposed method allows varying any parameter of a circuit, including the simulation settings and exploits the specific structure of the ATP-EMTP software. In the implementation of the method, Matlab software is used to control the execution of the ATP solver. Two examples are shown, for both time domain and frequency domain studies, where the sensitivity of maximum overvoltages at transformer terminals and the admittance resonances in a radial of an offshore wind farm to a change of the collection grid cable parameters is investigated.

Keywords: ATP-EMTP, parametric variation, sensitivity studies, OWF.

I. INTRODUCTION

There is often a need in simulations of electromagnetic transients for testing a given phenomenon's sensitivity to variations in one or more parameters of the circuit. Modern electromagnetic transient programs (EMTP), such as ATP-EMTP or PSCAD allow running such multivariate analysis only for specific cases. In case of ATP, one can for example use a statistical switch to statistically vary the switching time of a circuit breaker, or use Pocket Calculator Varies Parameters (PCVP) to vary most of the parameters of the circuit within a given range. As the PCVP is a powerful tool, it cannot change parameters of models generated by external routines, such as cable or line models. The possibility of variation of cable parameters, especially length, is important, e.g. for studies of resonances in cable systems of wind farms or high frequency interactions between electrical components in power systems.

This paper summarizes the most important methods of doing parametric variation studies in one of the EMT programs, namely ATP-EMTP, and shows in detail how to implement a method to vary any parameter of a circuit, including cables and overhead lines, using external scripting and Matlab. The same method could also be implemented using other programming languages, e.g. Fortran, which; however, is not

presented in the paper.

The paper is structured as follows. Section II introduces ATP-EMTP and shows how the specific structure of the program allows varying circuit elements externally and thus allows implementing the parametric variation method. Section III gives brief description of important build-in features of ATP-EMTP allowing to automatically vary chosen parameters of a circuit. Similar features can also be found in other EMT programs. The implementation of parametric variation studies of all parameters of the circuit is presented in section IV, while section V shows two examples of implementation of the method.

II. DESCRIPTION OF ATP-EMTP AND ITS STRUCTURE

ATP EMTP is a DOS-based software tool for digital simulation of electromagnetic as well as electromechanical transients. It uses the trapezoidal rule of integration to solve a circuit's differential equations in time domain but it can also be used to calculate the frequency response of phasor networks. It comprises of a variety of electric component models, including transformers, rotating machines, transmission lines and cables. It is widely used to simulate complex electrical and control systems [1].

The ATP-EMTP program consists of a DOS-based solver, *tpbig.exe*, and a number of supporting programs, (Fig.1), which communicate with each other via disk files.

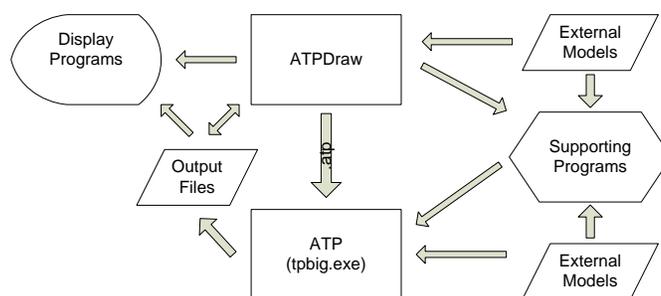


Fig. 1. Simplified representation of the relations between different programs in the structure of the ATP-EMTP system.

The *tpbig.exe* is the heart of the ATP-EMTP environment and is used to calculate the required variables of an electrical system which is described in a text file with an extension *.atp*. The *.atp* file has a strictly defined format of describing the circuit, where the information is given in a way resembling old Fortran cards. The rules how to properly create and format an *.atp* file are described in a 1170 page long manual, the ATP-Rulebook [2]. As such a way of describing a desired electrical system is tedious and very error prone; a number of dedicated

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graphical user interfaces (GUI's) are available, with ATPDraw being the most popular. ATPDraw is a GUI, where the user can draw and describe most of the properties of an electric system and the program translates it to a properly formatted *.atp* file and runs the *tpbig.exe*.

A number of models of electrical components exist which cannot be directly calculated by the solver and therefore need separate programs or routines to calculate their parameters and to translate the information to a proper format. Often in such cases the *tpbig.exe* is used as a pre-processor. Those supporting programs are used e.g. to calculate parameters of transmission lines and cables (Line Constants, Cable Constants and Cable Parameters), generate frequency-dependent line models (models: Samlyen, J.Marti and Noda), calculate model data of transformers including saturation. The supporting routines might also be run directly from the ATPDraw or are omitted and the data is created directly in ATPDraw.

One can also create one's own model or a part of a circuit outside ATPDraw and include it into main model with \$Include function which includes the path to a file describing the model in *.atp* file. This file (library file, *.lib*) must come in a pre-defined format specified by Data Base Module (DBM) of ATP. Such a file is made of a header, describing the position of the parameters, the data describing the component or a circuit and the specification of the parameters [3].

The ATP-EMTP allows to perform parametric-variation studies, i.e. automated studies, where one or more parameters of the circuit is varied a number of times within a given range. A short description of most popular methods is given in the next section. Those methods cannot modify component models which were created by supporting programs, such as e.g. cable models. However, such studies can still be done, by exploiting the seemingly complicated structure of the ATP-EMTP system comprised of a number of programs communicating with each other via disk files. The details of such a method are given in sections IV and V.

III. PARAMETRIC VARIATION METHODS IN ATP-EMTP

The ATP-EMTP and ATPDraw have several features allowing to perform parametric variation studies, depending on the parameter to vary.

If one investigates the influence of the time of a breaker operation on e.g. the magnitude of overvoltages, then a statistical/systematic switch can be used in ATPDraw.

Pocket Calculator Varies Parameters and \$Parameter are two powerful features of ATP which can be employed to perform parametric variation studies with calculation of parameters. They can change any internal parameter of the circuit; however, they cannot be used in situations when a model of a component is created by one of the supporting routines, as in case of line or cable models.

IV. IMPLEMENTATION OF PARAMETRIC VARIATION METHOD

The proposed method for performing parametric studies with any circuit parameter exploits the ATP-EMTP specific structure explained in section II. In most situations the solver

communicates with external programs and routines via disk files of specific structure and extension, as shown in Fig. 1. It is possible to modify those files and execute the solver with new data set by a simple text editor. Usually, the solver is executed from the GUI once and the output files are read and displayed either by GUI or by an external program after the execution. In our case, we will run the solver multiple times, each time with changed set of parameters and each time saving the selected output variables to disk. In order to do so, we will skip the GUI and use Matlab instead to run the solver. This can be done by any other programming language capable of running DOS-programs and executing DOS commands, as e.g. Fortran. The advantage of using Matlab is that it allows executing the *tpbig.exe*, import and store output data, do calculations based on the output data and display the results. It can be used as a substitute for both the GUI and the displaying programs of ATP-EMTP system.

The flow-chart showing general description of the algorithm is shown below.

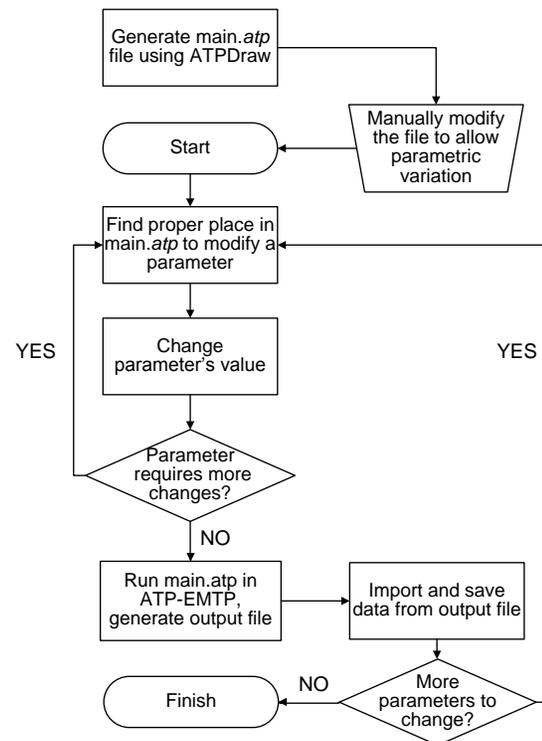


Fig. 2. Flow chart showing the main structure of the implemented algorithm. Figure modified after [4].

The following section gives details about the most important steps of the algorithm.

1. The description of an electrical circuit of interest needs to be done according to the ATP-Rulebook. The easiest way to do that is by using ATPDraw and simply copying the *.atp* file.
2. It is often necessary to manually adjust the generated *.atp* file. The most common changes are changes of paths to external files (e.g. *.lib* or *.pch* files) to allow use of Matlab-altered models. An example is shown in section V.B.

- The algorithm works by opening (Matlab *fopen*) and modifying the *.atp* file in places of interest. Before the algorithm starts, one needs to find the proper coordinates of such places. This can be done e.g. by measuring the number of spaces from the beginning of the file in a word processor or by using *fread* command in Matlab to search the file automatically. Each parameter to vary should have the pointer.
- It needs to be remembered that different types of parameters of a circuit might have different format and a strictly defined length in the *.atp* file. Therefore, it is necessary to consult the ATPRulebook.
- After modification of the value of chosen parameters the *.atp* file should be closed (*fclose*). The file can then be run using *dos* function.

V. EXAMPLES

The following two examples will illustrate the use of the created system and show the details of the script for the parametric variation. The examples show results of time simulation (example 1) and frequency sweep (example 2) at one radial of an offshore wind farm. In both cases the sensitivity of investigated variables to the change of the cable's length and its sheath's resistivity will be shown.

In both examples the length of each cable section is varied from 200 m to 700 m in steps of 20 m and the resistivity of a sheath of each cable might have three values: $1.72e-8$, $2.06e-8$, $2.58e-8 \Omega/m$. The length of the cable will influence the frequency of oscillation during energization of a radial and the change of sheath resistivity should influence the damping.

A. Wind farm's description

The investigated wind farm is comprised of a single radial with four turbines, as shown in Fig. 3.

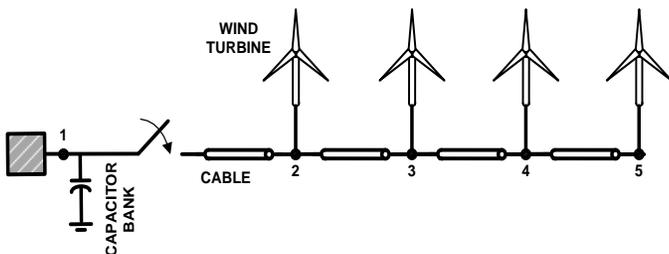


Fig. 3. Simplified single phase diagram of the investigated radial in a wind farm.

The voltage level on a radial is 10kV. The export system (or the MV side of a farm transformer) is represented by an ideal voltage source behind a series connection of 0.75Ω resistance and $19.2mH$ inductance. A lumped capacitance of $15 \mu F$ represents a capacitor bank. There are four cable sections in the radial, all made of the same length of $50mm^2$ cable. The wind turbines are represented by a 100kVA wind turbine transformer, 10/0.69 kV, Dyn. The transformer LV side is opened, which is not a normal case.

The cables are represented by J.Marti model with a transformation matrix calculated at 10 kHz. The cable's

geometrical parameters are shown in Table I.

Table I. Geometrical and physical data of a 50mm² cable

Parameter	Value	
	Core	Sheath
Inner radius [m]	0	0.0083
Outer radius [m]	0.004	0.0108
Resistivity, ρ [$\Omega \cdot m$]	$1.72e-8$	$1.72e-8$
Relative permeability of the conductor material, μ , [H/m].	1	1
Relative permeability of the insulator material outside the conductor, μ (ins), [H/m].	1	1
Relative permittivity of the insulator material outside the conductor, ϵ (ins), [F/m]	2.8817	2.3
Total radius of a cable [m]	0.0168	

The model of a 100kVA transformer is a black box model based on frequency domain measurements of a short circuit admittance matrix. The measurements were performed with the use of sweep frequency response analyzer (sFRA) [5] in frequency range of 20Hz to 20MHz [6].

The approximation of the admittance matrix is done via rational modelling using Vector Fitting [7] with 75 common poles and inverse weighting of matrix elements. The accuracy of the model is improved by incorporating additional measurements of the zero sequence system, as in [8], and the use of mode-revealing transformation derived from the admittance eigenvector matrix [9]. The passivity of the model was enforced by [10], and finally, the equivalent lumped RLC electrical network was generated and included in the ATP-EMTP model of a farm via \$Include.

The positive sequence voltage ratio from high to low and from low to high, calculated from the passive model, is shown in Fig. 4

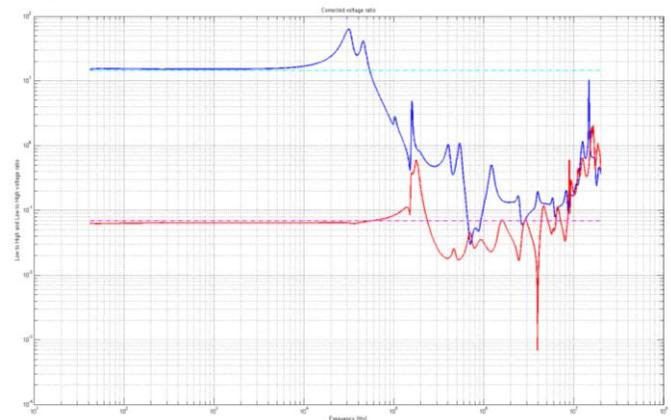


Fig. 4. Positive sequence voltage ratio from high to low (red) and from low to high (blue) with their respective theoretical values. Voltage ratio calculated from the passive model of 100 kVA transformer.

B. Time domain study

The purpose of this study is to show the sensitivity of the overvoltages at the terminals of WT transformers during radial energization to changes in the length of the radial and the resistivity of cable's sheath.

The breaker is closed at the beginning of the simulation. An ideal breaker model is used and each pole is closed at a

different time, with the pole on phase *A* closing at V_{max} .

The circuit is built in ATPDraw and the *.atp* file is generated. The *.atp* file will not be changed during parametric variation study as the only changes will be done to a cable model, which is added to the simulation as an external library via \$Include. It is useful to use *Insert \$Prefix and \$Suffix cards* request in ATP Settings, which will add the path to external models and their extension (*.lib*) to the beginning of *.atp* file. In our case there is only one cable model used, therefore there is only one change of parameter in each loop's iteration.

The pseudo code for this example is given below.

```

for all lengths of cable
  • Modify the cable .dat file by a proper
  length.
  for all values of Rho
    • Modify the cable .dat file by a
    proper value of resistivity.
    • Generate new cable model in DBM
    format
    • Run ATP simulation
    • Change ATP output file to .mat
    • Load the data to workspace
    • Save proper variables
    • Clear unneeded variables
  end
end
end

```

The cable model in the proper DBM format can be generated in the following steps:

1. Use ATPDraw LCC component to describe the cable parameters and model type. Run ATP, which should create a set of files on the disk (in the project folder).
2. Copy the created *.dat* file to a folder with simulation data. This file will be used to create the necessary DBM description of the cable model.
3. Run the *.dat* file in ATP. In Matlab, one can use command *dos*, e.g.

```
dos(['C:\ATP\tools\runATP.exe cable.dat'])
```

4. A set of files should be generated by ATP if the *.dat* file was proper, one of them being a punch file, *.pch*. This file describes the model of the cable but it is not in the proper DBM format yet. The details about DBM are given in section XIX-F of ATP-Rulebook.
5. One of the ways to create the proper DBM format is to create a new file with extension *.dbm* which will contain a proper suffix and prefix and a body copied from the *.pch* file. See also section III in case of a single-core cable, the *.dbm* file could be:

```

BEGIN NEW DATA CASE --NOSORT--
DATA BASE MODULE
$ERASE
ARG,IN__A,OUT__A
/BRANCH
=== Here comes the body of the .pch file ===
BEGIN NEW DATA CASE
C
$PUNCH
BEGIN NEW DATA CASE
BLANK

```

6. It is essential to create this file without any formatting. One can create two text files (in simple word processor, e.g. Notepad in Windows), first containing prefix (four lines before the *.pch* file's content) and the other-suffix (last five lines, after the *.pch* file's content) and then use command system with copy in Matlab to join them with *.pch* file, remembering about the proper order of files. The obtained *.dbm* file should be run with ATP.
7. If the ATP solver runs successfully, a new *.pch* and/or a *.lib* file should be created on the disk. If only punch file was created, it can be renamed to *.lib*.
8. This procedure should be repeated each time any parameter of a cable is changed.

C. Frequency domain study

The purpose of this study is to show the sensitivity of the driving-point admittance at the terminals of transformers to changes in the length of radial and the resistivity of cable's sheath.

Here, the breaker is not included in the model and the driving point admittance is obtained by connecting a voltage source of 1V to a given terminal and measuring the current flowing into the circuit. The value of current is then corresponding to the admittance. The admittance for different frequencies can be obtained by varying the frequency of the source, using the *Frequency scan* setting. The chosen frequency band of the simulation was 20 Hz to 2 MHz with 1000 points per decade.

The points in the radial, where the driving-point admittance was measured, are indicated by numbers from 1 to 5 in Fig. 3. Five separate models had to be created as only one driving-point admittance can be calculated per model.

The principle for automatic variation of cable lengths and sheath resistivity is the same as in previous example. Some simulation time was saved by using cable models generated in previous example.

VI. RESULTS

In the time domain case the largest overvoltages after closing the breaker are expected at phase *A* where the breaker was closed at V_{max} . The voltage wave will travel along the radial and reflect from the last turbine, which has much greater impedance, thus almost doubling its magnitude. This can be seen in Fig. 5.

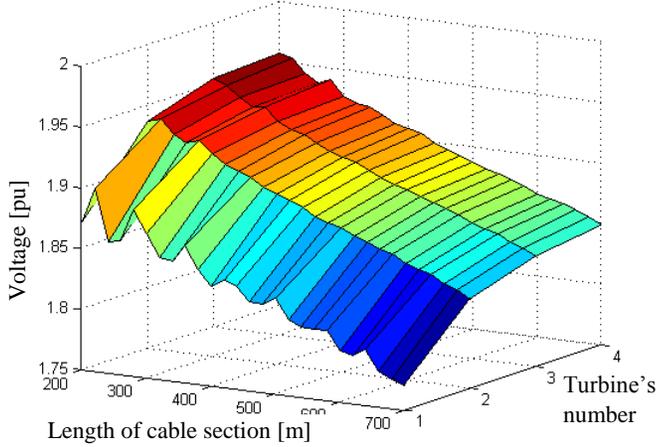


Fig. 5. Maximum voltage at 10kV terminal of phase A of wind turbine transformers for varied length of cable sections.

The change of the cable length has the greatest influence on the maximum voltage at the first turbine in a radial, where the difference between the smallest and the largest overvoltage magnitude is almost 15%.

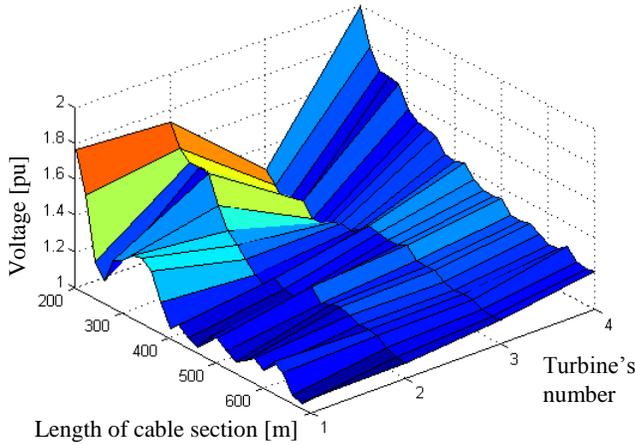


Fig. 6. Maximum voltage at 690V terminal (LV side) of phase A of wind turbine transformers for varied length of cable sections.

The maximum overvoltages at phase A related to the length of the cable section have different characteristic at LV side of WT transformers as compared to the HV side, as shown in Fig. 6. This is consistent with the fact that the voltage ratio of the transformer varies significantly at higher frequencies, as was shown in Fig. 4.

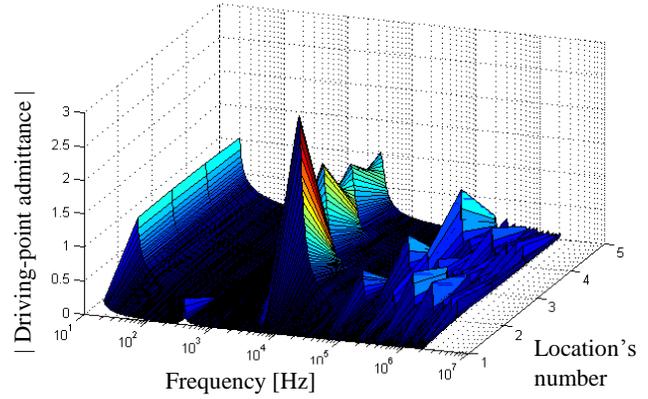


Fig. 7. Driving-point admittance vs. frequency at all measured locations of the WF for length of each cable section of 220m.

Fig. 7 shows driving point admittance for frequencies from 20 Hz to 2 MHz for all measured locations. At the first location there is only one resonance, at around 298 Hz, corresponding to the resonance frequency of the source inductance and capacitance of a capacitor bank, which is $\frac{1}{2\pi\sqrt{LC}} = 296.6$ Hz. This resonance is not seen at any of the turbines, where the first one occurs in the kilohertz range.

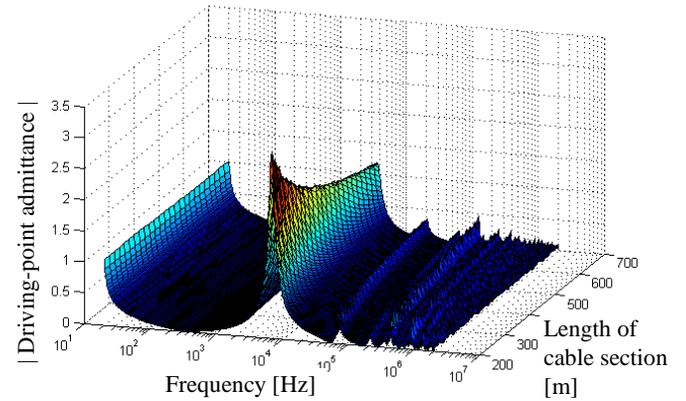


Fig. 8. Driving-point admittance at location 2 (WT1) for different cable lengths.

The driving-point admittance at the second location (WT1) for various cable lengths is shown in Fig. 8. One can notice the shift of the resonances to lower frequencies with increase of the cable length. This is expected as the increase of cable's length increases the travelling time of the wave along the cable and thus decreases the resonance frequency.

VII. DISCUSSION

The simulations were done in a PC equipped with an AMD Phenom II, 3GHz processor, 16GB of RAM and running under MS Windows XP x64. 78 changes of parameters were made for the time domain study and $5 \cdot 78 = 390$ for frequency domain studies. The average time of computations per iteration was 0.35 min and 2.05 min, for time- and frequency- domain studies, respectively. The relatively large amount of time for frequency domain studies was due to wide band model of a transformer used, which is a six-port

approximated with 75 poles and described by an equivalent lumped RLC network.

Due to the very strict format of ATP files, where every parameter has its unique place in the file with strictly defined beginning and end, setting up the parametric variation simulations can be a very tedious process which might take a considerable amount of time, especially for inexperienced users.

The proposed method allows controlling all parameters of the model and all ATP settings for each ATP's simulation dynamically. Therefore, a proper algorithm employing regression techniques or search methodologies can control the number of execution times and values of parameters of the simulation in order to minimize the number of iterations. Choose of a proper algorithm will depend on the investigated problem and might vary considerably. The structure of the proposed method can be easily modified to allow decision making based on the results of transient simulations for each iteration. In such case the flow-chart from Fig. 2 should be exchanged by the following one.

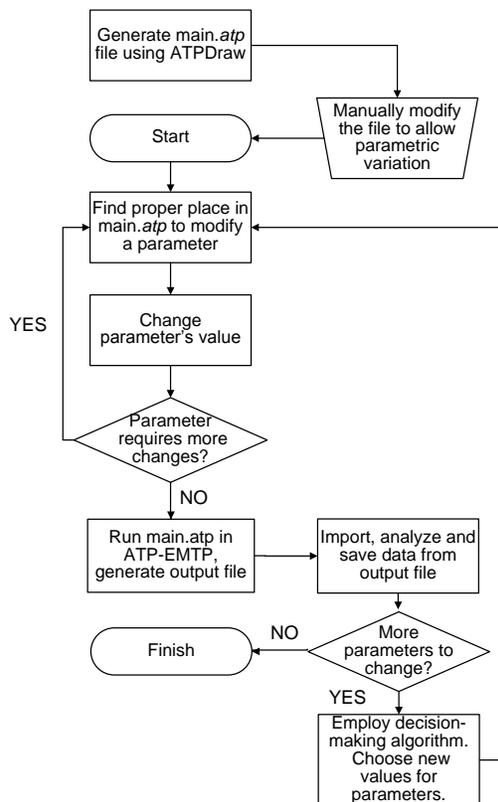


Fig. 9. Flow chart showing the main structure of the implemented algorithm allowing for use of decision-making algorithm. Figure modified after [4].

VIII. CONCLUSIONS

The paper presents an algorithm for, and shows the implementation of a method to perform parametric variation studies using an electromagnetic transients program. This kind of studies are used to investigate the sensitivity of a given phenomena to variation of parameters in an electric system.

The proposed method allows varying any parameter of a circuit, including the simulation settings. It exploits the specific structure of the ATP-EMTP software which uses disk files to communicate between the solver and various supporting routines. In the implementation of the method the Matlab software is used to control the execution of the ATP solver. The method is demonstrated by application to an offshore windfarm, with simulations done in both frequency and time domain.

The proposed method is fast and very powerful; however, the implementation might be tedious and time consuming, as it needs a deep knowledge of a very specific and strict structure of the modified ATP-EMTP files. It is; therefore, recommended to use the method in cases when ATP-EMTP's build-in parametric variation methods cannot be used, e.g. for simulations involving change of parameters of transmission cables or lines.

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