MATPOWER FUBM

Quick Guide

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MATPOWER-FUBM

1. Flexible Universal Branch Model (FUBM) Description

Matpower's© model currently simulates the classical branch model in series with an ideal transformer. It is well known for being effective in traditional AC OPF analysis. The FUBM fuses Matpower's model with the voltage source converter (VSC) model, and sets controls as variables to add flexibility to the simulations. The result is a powerful and yet simple model that allows MATPOWER optimal power flow analysis tool to adequately simulate the hybrid AC/DC grids and their controls. The FUBM model is shown in Fig. 1.

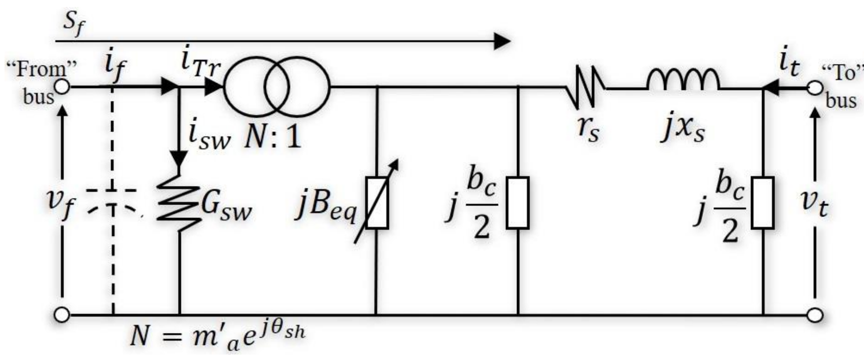


Figure 1. Flexible Hybrid AC/DC Universal Branch Model.

1.1. Elements and In-Modelling

Being a universal model, the full FUBM design contains one internal model (in-model) per transmission element of the power grid (one element at a time). FUBM's internal components are shared, and have distinct purposes depending on the desired element to be modelled. Table I is a configuration guidance for the selection of the desired model.

TABLE I
SETTINGS FOR THE DESIRED IN-MODEL

Parameter	Branches	CTT	PST	VSC	STATCOM
G_{sw}	0	0	0	$*^a$	$*^a$
B_{eq}	0	0	0	$*^a$	$*^a$
θ_{sh}	0	0	$*^a$	$*^a$	$*^a$
k_2	1	1	1	$*^a$	$*^a$
m_a	1	$*^a$	1	$*^a$	$*^a$
b_c	$*^a$	0	0	0	0
r_s	$*^a$	$*^a$	$*^a$	$*^a$	$*^a$
x_s	$*^a$	$*^a$	$*^a$	$*^a$	$*^a$
v_f	free	free	free	free	fixed

$*^a$: *in-model* parameter

2. Setting up a controlled AC/DC grid using FUBM

2.1. AC/DC grids and DC Voltage Control

In order to set up a DC grid on top of an AC grid at least one VSC is necessary to be the linker.

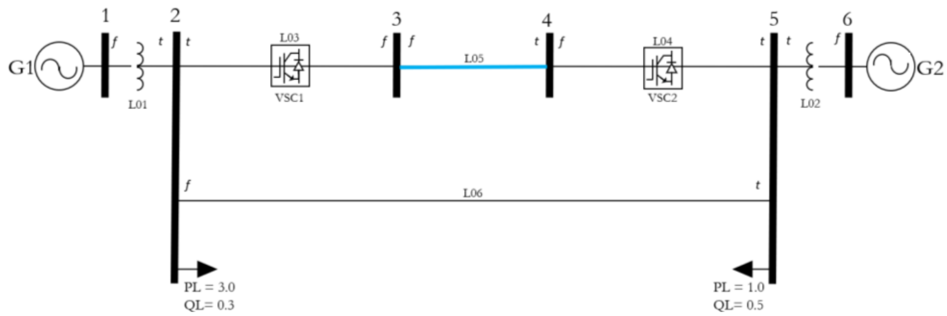


Figure 2 Controlled AC/DC grid

Consider the grid of Figure 2. It includes two VSC. The first one, will be a converter type I. The job of this type of converters is to absorb or supply the necessary reactive power in their "to" side so that the reactive power in the "from" side is Zero. Thus, VSC type I must meet the Zero Constraint ($Q_t = 0$). This is possible by varying the value of the variable B_{eq}.

In order to activate a VSC type I in the Matpower case, we simply need to set a number 1 in the branch matrix column with the index called "CONV" and set up limits for the control variable B_{eq} as shown below in colour Red at Fig. 3.

```
%% branch data
%   fbus tbus   r       x      b   ...  CONV  ...  K2   BEQ_MIN  BEQ_MAX
mpc.branch = [
    001  002    0.001   0.10   0         0          1    0        0
    002  005    0.0500  0.50   0         0          1    0        0
    003  002    0.0001  0.15   0         1          1    -0.5     0.5
    003  004    0.05    0      0         0          1    0        0
    004  005    0.0001  0.15   0         2          1    -0.5     0.5
    006  005    0.001   0.10   0         0          1    0        0
];
```

Figure 3 Setting up a VSC type I

Traditionally it is desirable to have a controlled voltage over the DC grid. VSC type II is used for this function, controlling the Voltage "from" side to a desired value $V_f - V_{f_{Set}} = 0$.

To activate the voltage control for the VSC type II, we need to set a number 2 in the branch matrix column with the index "CONV", set up limits for the control variable B_{eq} as shown below in colour Blue at Fig. 3, and set the desired voltage in [pu] for the branch matrix column with the index "VF_SET".

Notice that in a multi terminal DC link, with n VSCs there must be at least $n-1$ VSC type I and no more than one VSC type II.

2.2. Voltage Droop Control

When VSC Voltage droop control is implemented, the active power injected to the DC grid will be a function of the VSC DC voltage. Equation below presents the traditional voltage-power $V_{mDC} \longrightarrow P_f$ standard droop control equation. The parameter k_{dp} represents the linear slope control. The set parameters for P_f^{set} , v_{mf}^{set} and k_{dp} can be set on the branch columns "PF", "VF_SET" and "KDP" respectively.

$$-P_f + P_f^{set} - k_{dp}\left(v_{mf} - v_{mf}^{set}\right) = 0$$

In order to activate a VSC type III in the Matpower case, we simply need to set a number 3 in the branch matrix column with the index called "CONV" and set up limits for the control variable B_{eq}. For solvability, in a MTDC grid with only VSCIII there must be a "slack VSC", that one should be set a number 4 in the branch matrix column with the index called "CONV".

2.3. VSC PWM Power Loss Calculation according to Standard IEC 62751-2

In MatPower-FUBM, VSC active power loss can be selected to be calculated with a constant value of G_{sw} or calculated according to the Standard IEC 62751-2 depending on the study.

To select a VSC power loss calculation using a constant G_{sw}, in the branch matrix column with the index "GSW" simply set a value for G_{sw} in [pu] as highlighted in Red as shown in Fig. 4:

```
%% branch data
%  fbus tbus    r        x       b        GSW        ALPHA1 ALPHA2 ALPHA3   ---
mpc.branch = [
    001 002     0.001    0.10    0  •••   0          0       0       0;
    002 005     0.0500   0.50    0        0          0       0       0;
    003 002     0.0001   0.15    0        0.001      0       0       0; %VSC1
    003 004     0.05     0       0        0          0       0       0;
    004 005     0.0002   0.35    0        0.001      0       0       0; %VSC2
    006 005     0.001    0.10    0        0          0       0       0
];
```

Figure 4 VSC loss setting for a constant Gsw

According to the Standard IEC 62751-2 the active power loss created by the switching of the PWM in the VSC, can be calculated as a quadratic function of the phase current of VSC valves. For the FUBM this current is the current "to" side i_t. Therefore, the Power loss is expressed as:

$$P_{VSC\ Loss\ IEC} = \alpha_3 I_t^2 + \alpha_2 I_t + \alpha_1 \quad \forall \ \ VSC\ elements$$

$$G_{sw} = {P_{VSC\ Loss\ IEC}} \Big/ {|V_f|^2} \quad \forall \ \ VSC\ elements$$

To activate the Standard IEC 62751-2 active power loss calculation for VSC, we just need to specify the α_1, α_2 and α_3 values as highlighted in red in Fig. 5. If a value of G_{sw} is provided it will be used as initial condition.

```
%% branch data
%  fbus tbus    r        x       b        GSW        ALPHA1  ALPHA2  ALPHA3   -----
mpc.branch = [
    001 002     0.001    0.10    0  •••   0          0       0       0;
    002 005     0.0500   0.50    0        0          0       0       0;
    003 002     0.0001   0.15    0        0.001      0.0001  0.015   0.02; %VSC1
    003 004     0.05     0       0        0          0       0       0;
    004 005     0.0002   0.35    0        0.001      0.0001  0.015   0.02; %VSC2
    006 005     0.001    0.10    0        0          0       0       0
];
```

Figure 5 Standard IEC 62751-2 active power loss for VSC setting

2.4. Active power controls

There are two elements with the ability of controlling the active power. The Phase Shifter Transformer (PST) and the VSC (of any type). The FUBM controls the power "from" side by varying the variable θ_{shift} for both elements to meet a desired setting. $P_f - P_{f_{Set}} = 0$.

In order to activate an element to control the active power, the desired power to be controlled must be set in [MW] at the branch matrix column with the index "PF", also set-up limits for the control variable θ_{shift} as highlighted below in colour Blue at Fig. 6. Notice that for any other element that is not controlling the active power, the Shifter min and max limits must remain -360 and 360 respectively.

```
%% branch data
%  fbus tbus   r        x      b    ...   PF    ...  BEQ_MAX SH_MIN  SH_MAX
mpc.branch = [
    001 002    0.001    0.10   0          0          0       -360    360;
    002 005    0.0500   0.50   0          0          0       -360    360;
    003 002    0.0001   0.15   0          0          0.5     -360    360;
    003 004    0.05     0      0          0          0       -360    360;
    004 005    0.0001   0.15   0          -0.5       0.5     -50.0   50.0;
    006 005    0.001    0.10   0          0          0       -360    360
];
```

Figure 6 Setting up Active Power Control

2.5. Reactive power controls

In a very similar way, there are two elements with the ability of controlling the reactive power. The controlled tap transformers (CCT) or traditionally called automatic tap changers, and the VSC (of any type). The FUBM controls the reactive power "to" side by varying the variable m_a. For the transformers, this variable would be the normal tap, and for the VSC will be the modulation amplitude m_a. Since the behaviour of these two variables is similar, they are represented with a single one. Thus, both elements can meet a desired setting. $Q_t - Q_{t_{Set}} = 0$.

In order to activate an element to control the reactive power, the desired power to be controlled must be set in [MVAr] at the branch matrix column with the index "QT", also it is necessary to set-up limits for the control variable m_a located in the columns "TAP_MAX" and "TAP_MIN" as highlighted below in colour Red at Fig. 7. Notice that for any other element that is not controlling the reactive power, both tap limits must remain with a value of one.

```
%% branch data                                          ...              ...
%   fbus tbus     r         x       b            QT           TAP_MAX TAP_MIN
mpc.branch = [
    001 002      0.001     0.10    0             0             1        1
    002 005      0.0500    0.50    0             0             1        1
    003 002      0.0001    0.15    0            -0.3           1.2      0.8
    003 004      0.05      0       0             0             1        1
    004 005      0.0001    0.15    0             0             1        1
    006 005      0.001     0.10    0             0             1        1
];
```

Figure 7 Setting up Reactive Power Control

2.6. AC Voltage Control

Voltage control in the AC side can be achieved by either a CCT or a VSC. The variable m_a as seen in subsection 2.3, is included in these two elements. In this case instead of using it to control the reactive power, it will be used to match a desired Voltage in the "to" side. $V_t - V_{t_{Set}} = 0$. Therefore, and element can control either the V_t or the Q_t but not both at the same time.

In order to activate an element to control the voltage "to" side, the desired voltage has to be set in [pu] for the branch matrix column with the index "VT_SET", also it is necessary to set-up limits for the control variable m_a located in the columns "TAP_MAX" and "TAP_MIN" just as it has been done in subsection 2.3. Again, for any other element that is not controlling the Voltage "to", both tap limits must remain with a value of 1. Fig. 8 exemplifies this setting.

```
%% branch data                                      ...
%   fbus tbus     r         x       b       VF_SET   VT_SET   TAP_MAX TAP_MIN CONV
mpc.branch = [
    001 002      0.001     0.10    0        0        0        1       1       0
    002 005      0.0500    0.50    0        0        0        1       1       0
    003 002      0.0001    0.15    0        0        1.099    1.2     0.8     1
    003 004      0.05      0       0        0        0        1       1       0
    004 005      0.0001    0.15    0        1.1      0        1       1       2
    006 005      0.001     0.10    0        0        0        1       1       0
];
```

Figure 8 Setting up AC Voltage Control

3. Simulating a case

To run a controlled AC/DC Newton Power Flow on the modified 30-bus system specified in the file `fubm_case_30_2MTDC_ctrls_vt2_pf_dp.m`, with the default algorithm options, at the MATLAB prompt, type:

```
runpf('fubm_case_30_2MTDC_ctrls_vt2_pf_dp')
```

To run a controlled AC/DC Optimal Power Flow on the modified 30-bus system specified in the file `fubm_case_30_2MTDC_ctrls_vt2_pf_dp.m`. The algorithm options should be adjusted as follows:

At the MATLAB prompt, type:

```
mpopt = mpoption('opf.ac.solver', 'MIPS',
'mips.max_it',5000,'opf.violation',1e-6);

runopf('fubm_case_30_2MTDC_ctrls_vt2_pf_dp',mpopt)
```

For your convenience, and apart from this quick guide, there is a small example script for you to run the test cases, this script is called "sim_fubm". This file is not necessary for the normal user, it is just an example.

All the mentioned options have been pre-set inside "sim_fubm". Inside the script you can select the desired test case to run by activating or deactivating the line of code with "%"as in Fig. 9.

```
%Run OPF
%[results] = mainopf('case9',mpopt);
[results] = mainopf('fubm_caseHVDC_qt',mpopt);
%[results] = mainopf('fubm_caseHVDC_vt',mpopt);
%[results] = mainopf('fubm_case_57_14_2MTDC_ctrls',mpopt);
%[results] = mainopf('fubm_case_30_2MTDC_ctrls_vt1',mpopt);
%[results] = mainopf('fubm_case_30_2MTDC_ctrls_vt2',mpopt);
```

Figure 9 Test cases

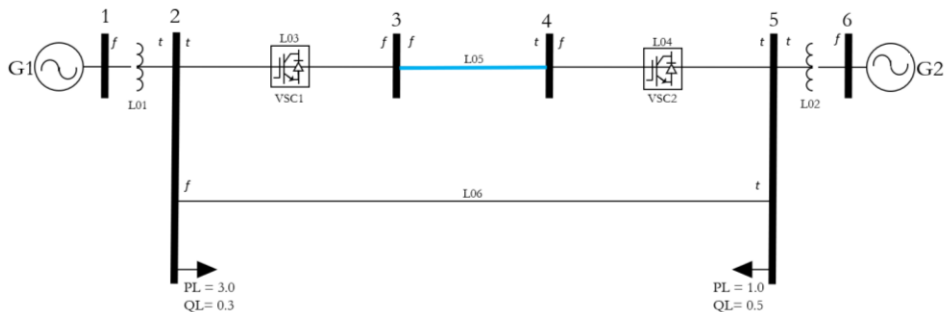
THAT'S IT! Now you can start simulating Flexible Controlled AC/DC power systems

Hope you enjoy it!

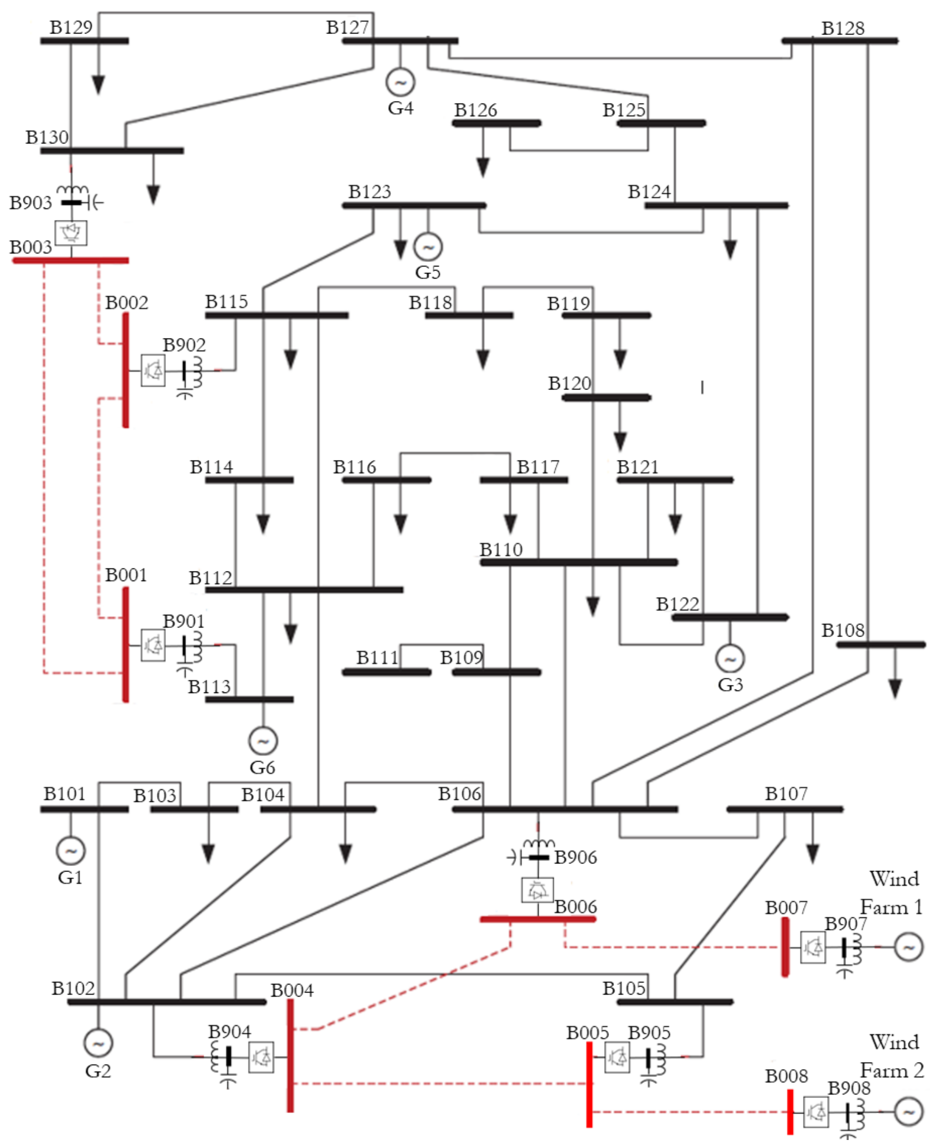
For questions email: abraham.alvarez-bustos@durham.ac.uk or snoop_and@hotmail.com

4. Diagrams

4.1. fubm_caseHVDC_qt/vt



4.2. fubm_case_30_2MTDC_FW_ctrls



4.3. fubm_case_57_14_2MTDC_ctrls