A MODELICA PACKAGE FOR BUILDING-TO-ELECTRICAL GRID INTEGRATION

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ABSTRACT

This paper presents the new Electrical package of the Modelica Buildings library. The package contains models for different types of sources, loads, storage equipment, and transmission lines for electric power. The package contains models that can be used to represent DC, AC one-phase, and AC-three phases balanced and unbalanced systems. The models have been successfully validated against the IEEE four nodes test feeder. An example shows how the models can be used to study the integration and control of renewable energy sources in a electric distribution grid.

INTRODUCTION

Residential and commercial buildings constitute nearly 70% of the overall electricity energy use in the United States. The integration of buildings and the distribution grid is important to guarantee a reliable grid operation. The need for sustainable and net zero energy buildings is increasing the fraction of renewable energy sources. Renewable sources like photovoltaics (PVs) and new types of loads such as electric vehicles, are intermittent. The increase of these loads and sources impacts the grid stability and reliability. In order to avoid problems, efficient transactions between buildings and the grid need to become a reality (Xue et al., 2014).

Building simulation tools have been successfully used to design high energy-performance buildings. Our contribution enhances the capabilities of simulation tools to address building-to-grid integration. We present the Electrical package, a package of the Modelica Buildings library [http://simulationresearch.lbl.gov/modelica] that is a free, open-source library for modeling of building energy and control systems. The Electrical package contains models for generation, consumption, storage, and transmission of electric power. The models can be used to scale from the building level up to the distribution level. The models have been successfully validated against IEEE tests and can be adopted by grid operators, planners, and researchers to design, control, and operate the grid. Those models can be integrated with thermal building simulation models to check the impact of advanced control strategies and demand response on the power quality of the distribution grid. Two applications are presented. The first is the validation of the models against the IEEE four nodes test feeder. The second is the analysis of the voltage levels in a district in which PVs are connected in an unbalanced configuration.

CONNECTORS

The Electric package uses a new type of generalized connector that has been introduced by Franke and Wiesmann (2014a) and is used by the Power Systems Library (Franke and Wiesmann, 2014b) and the Electric Power Library (Modelon, 2014).

The Modelica Standard Library (MSL) version 3.2.1 differs depending on the type of electric system being modeled. For example, DC and AC continuous time systems have a connector that differs from the one used by AC models, which use the quasi-stationary assumption.

The generalized electrical connector overcomes this limitation. It uses a paradigm that is similar to the one used by the `Modelica.Fluid` connectors.

```
connector Terminal
  "Generalized electric terminal"
  ...
  replaceable package PhaseSystem =
     PhaseSystems.PartialPhaseSystem
     "Phase system";
  PhaseSystem.Voltage v[PhaseSystem.n]
     "Voltage vector";
  flow PhaseSystem.Current i[PhaseSystem.n]
     "Current vector";
  PhaseSystem.ReferenceAngle
    theta[PhaseSystem.m]
    "Optional vector of phase angles";
end Terminal;
```

The connector has a package called `PhaseSystem` that contains constants, functions, and equations of the specific electric domain. This allows to represent different electrical domains using the same connector, reusing the same standardized interfaces.

As the electrical connectors of the MSL, the `Terminal` has a vector of voltages as effort variables and a vector of currents as flow variables. The connector has an additional vector that represents the reference angle `theta[PhaseSystem.m]`. If

PhaseSystem.m>0 the connector is overdetermined because the number of effort variables is higher than the number of flow variables. The overdetermined connectors are defined and used in such a way that a Modelica tool is able to remove the superfluous but consistent equations, arriving at a balanced set of equations based on a graph analysis of the connection structure. The models in the library uses constructs specified by the Modelica language to handle this situation (Olsson et al., 2008).

PHASE SYSTEMS

The `PhaseSystem` is a package that contains constants, equations, and functions that provide a mathematical representation of a given electrical domain. By replacing the `PhaseSystem`, it is possible to seamlessy switch from one domain to an other. The package defines:

- `PhaseSystem.n` – the number of independent voltage and currents.
- `PhaseSystem.m` – the number of reference angles,
- functions that compute the system voltage, currents, phases, powers, etc.

More details about the `PhaseSystem` can be found in Franke and Wiesmann (2014a).

DC PACKAGE

The `Electrical.DC` package contains models that represent direct current systems. The mathematics needed to describe DC systems is contained in the package `PhaseSystems.TwoConductor`, where `n=2` and `m=0`. This package assumes that the voltage vector at the connector is the voltage drop while the reference angle is 0, as it is not needed in the DC domain.

Ideal voltage source

The ideal voltage source is a simple model that specifies the voltage increase of an ideal generator without any loss as

$$V_1 - V_2 = V, \tag{1}$$

where V_1 and V_2 are the two components of the voltage vector specified by the connector. The following code snippet shows how the model extends a generalized source model `Electrical.Interfaces.PartialSource` and then redeclares the phase system.

```
model ConstantVoltage
  "Model of a constant DC source"
extends
   Electrical.Interfaces.PartialSource(
    redeclare package PhaseSystem =
      PhaseSystems.TwoConductor,
    redeclare Interfaces.Terminal_p terminal,
    ...)
    parameter Voltage V
      "Value of the constant voltage";
equation
  terminal.v[1] = V;
  terminal.v[2] = 0;
  sum(terminal.i) = 0;
end ConstantVoltage;
```

Load model

The load mode can be used to represent a system that either produces or consumes power. The constitutive equation of the load is

$$(V_1 - V_2)i_1 = P_{LOAD}, \tag{2}$$

where V_1 and V_2 are the two components of the voltage vector specified by the connector, i_1 is the current leaving the component, and P_{LOAD} is the power. By convention, if $P_{LOAD} > 0$ the load is producing power, otherwise it is consuming power. The power P_{LOAD} can be specified either as a parameter or an input.

Linearized load model

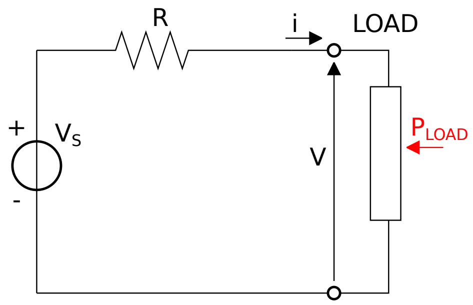

Figure 1: This simple DC circuit, in which the power consumed by the load is prescribed, leads to a nonlinear system of equations.

Consider the simple DC circuit shown in Figure 1, where V_S is a constant voltage source and R is a line resistance. The load has a voltage V across its electrical pins and a current i. If the power consumed by the load is P_{LOAD}, the equation that describes the circuit is

$$V_S - R\,i - \frac{P_{LOAD}}{i} = 0\,. \tag{3}$$

To compute the current i that is drawn by the load, a nonlinear equation has to be solved. If the number of loads increases, as typically happens in grid simulations, the size of the system of nonlinear equations to be solved increases too, causing the numerical solver to slow the simulation. A linearized load model can solve such a problem.

The first step to linearize the load model is to define its nominal voltage V_{nom}, around which it will be linearized. The constitutive equation of the load

$$i = \frac{P_{LOAD}}{V} \tag{4}$$

can be linearized by a Taylor series expansion around the nominal voltage $V = V_{nom}$ as

$$
\begin{aligned}
i &= \left[\frac{P_{LOAD}}{V}\right]_{V=V_{nom}} \\
&\quad +(V-V_{nom})\left[\frac{\partial}{\partial V}\frac{P_{LOAD}}{V}\right]_{V=V_{nom}} \\
&\quad +o((V-V_{nom})^2)
\end{aligned}
\tag{5}
$$

that leads to the linearized formulation

$$
i = \left(\frac{2}{V_{nom}} - \frac{V}{V_{nom}^2}\right) P_{LOAD}. \tag{6}
$$

The linearized error grows proportional to $(V - V_{nom})^2$. When multiple loads are connected in a grid through cables that cause voltage drops, the dimension of the system of nonlinear equations increases linearly with the number of loads. This nonlinear system of equations introduces challenges during the initialization, as Newton solvers may diverge if initialized far from a solution. The initialization problem can be simplified using the `homotopy` operator. The homotopy operator uses two different types of equations to compute the value of a variable: the actual one and a simplified one. The actual equation is the one used during the normal operation. During initialization, the simplified equation is first solved and then slowly replaced with the actual equation to compute the initial values for the nonlinear systems of equations. The load model uses the homotopy operator, with the linearized model being used as the simplified equation. This numerical expedient has proven useful when simulating models with more than ten connected loads.

```
// How the homotopy operator is
// used in the DC load model
i[1] = - homotopy(
     actual =
       P/(v[1] - v[2]),
     simplified =
       P*(2/V_nominal -
       (v[1] - v[2])/V_nominal^2)
     );
...
```

Renewable energy sources and batteries

The DC package also has models for renewable energy sources such as PV panels and wind turbines that natively produce DC power. The renewable sources are modeled with loads that produce a variable amount of power that depends on either the solar irradiation or the wind speed. The package contains also a simple battery model that stores electrical energy and accounts for different losses during the charge or discharge phase.

ASSUMPTIONS FOR ALL AC PACKAGES

The `Electrical.AC` package contains component models for AC systems. The mathematics that describes AC systems is contained in the package `PhaseSystems.OnePhase`, in which `n=2` and `m=1`. The AC models that are part of the library can use two different assumptions.

The first assumption is that the frequency is modeled as quasi-stationary, assuming a perfect sine wave with no higher harmonics. Voltages and currents are considered as sine waves and just their amplitudes and phase shifts are taken into account during the analysis. With such an assumption, electric quantities can be represented with a phasor, i.e., a vector in the complex plane.

The second assumption is the so-called dynamic phasorial representation. The basic idea of the dynamic phasorial representation is to account for dynamic variations of the amplitude and the angle of the phasors. With such an approach, it is possible to analyze faster dynamics without directly representing all the electromagnetic effects and high-order harmonics (for more details Stankovic et al. (1999); Stankovic and Aydin (2000)).

AC ONE PHASE

We will now present some models of the `Electrical.AC.OnePhase`. The models contained in this package are particularly important because other AC domains can be represented by reusing these models.

Ideal voltage source

The ideal voltage source is a simple model that specifies the voltage increase of an ideal generator without losses

$$
[V_1, V_2] = V[cos(\theta), sin(\theta)], \tag{7}
$$

where V_1 and V_2 are the two components of the voltage vector that represent the phasor of the connector, while θ is the phase angle of the phasor. The following code shows how this model extends the generalized source model `Electrical.Interfaces.PartialSource` and redeclares the phase system.

```
model FixedVoltage
  "Model of a fixed voltage AC source"
extends
   Electrical.Interfaces.PartialSource(
    redeclare package PhaseSystem =
      PhaseSystems.OnePhase,
    redeclare Interfaces.Terminal_p terminal,
    ...)
    parameter Voltage V = 120
      "RMS value of the voltage";
    parameter Frequency f = 60
      "Frequency of the source voltage";
    parameter Angle phi = 0
      "Phase shift of the source";
    Angle thetaRel
      "Relative angle of the source";
equation
  if connection.isRoot(terminal.theta) then
    PhaseSystem.thetaRef(terminal.theta) =
    2*Modelica.Constants.pi*f*time;
```

```
    end if;

    thetaRel = PhaseSystem.thetaRel(
                 terminal.theta);
    terminal.v[1] = V*cos(thetaRel + phi);
    terminal.v[2] = V*sin(thetaRel + phi);

end FixedVoltage;
```

Impedances

This model represents a generalized impedance. The impedance can be purely resistive, purely inductive, purely capacitive, inductive, or capacitive. The value of the resistance, inductance, and capacitance can be specified by parameters or inputs. The model of the impedance is

$$[V_1, V_2] = ZI = [Ri_1 - Xi_2, Ri_2 + Xi_1], \qquad (8)$$

where I is the current phasor specified by the connector, i_1 and i_2 are its two components, and $Z = [R, X]$ is the impedance, with the first component R being the resistance and the second component X being the reactance. When the impedance is inductive, the reactance is $X = \omega L$; otherwise it is $X = -1/(\omega C)$.

Loads

As for the DC case, the load model is able to represent a system that produces or consumes power. In the AC domain, the power is the apparent power S computed as

$$S = [P, Q] = VI^* = [V_1 i_1 + V_2 i_2, V_1 i_2 - V_2 i_1], \qquad (9)$$

where P is the active power measured in watts, and Q is the reactive power in VAR. The overall unit of the apparent power S is VA. The load model has two inputs: one to represent the active power consumption P and one to represent the power factor $cos(\phi) = atan2(Q, P)$ that is the angle of the complex power vector S.

The load model contains nonlinear equations that relate the current to the voltage. The nonlinearity is easier to see when equation (9) is written

$$i_1 = \frac{PV_1 + QV_2}{V_1^2 + V_2^2}, \qquad (10a)$$

$$i_2 = \frac{PV_2 - QV_1}{V_1^2 + V_2^2}. \qquad (10b)$$

This voltage dependency leads to a nonlinear system of equations when modeling electrical networks that have AC loads. Unfortunately, in the AC case, the nonlinearity is more complex because it involves the two components of the vector. In addition the solution of the nonlinear equation has to satisfy an algebraic constraint that is represented by the ratio of the active and reactive power of the load. Figure 2 shows the shape of the nonlinear function that determines i_1 of a load given the two voltage components, when the AC load is purely resistive.

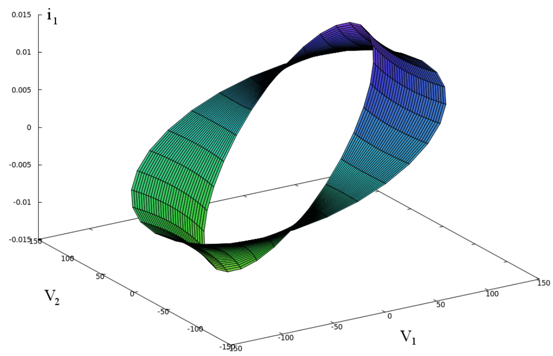

Figure 2: The nonlinear relationship between the current and the voltage for a purely resistive AC load.

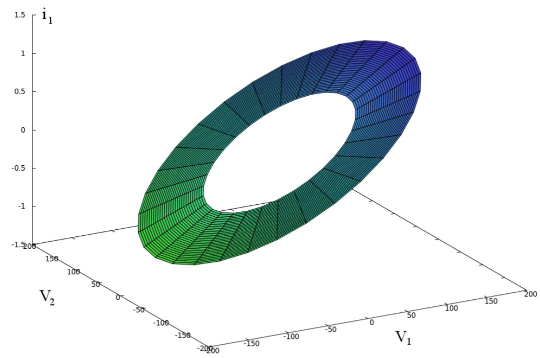

Figure 3: The linearized relationship between the current and the voltage for a purely resistive AC load.

Given the constraints and the two-dimensional nature of the problem, it is difficult to find a linearized version of the load model. A solution could be to divide the voltage domain into sectors, and for each sector compute the best linear approximation. However the selection of the proper approximation depending on the value of the voltage can generate events that increase the simulation time. For these reasons, the linearized model assumes a voltage that is equal to the nominal value,

$$i_1 = \frac{PV_1 + QV_2}{V_{RMS}^2}, \qquad (11a)$$

$$i_2 = \frac{PV_2 - QV_1}{V_{RMS}^2}, \qquad (11b)$$

where V_{RMS}^2 is the root mean square (RMS) nominal voltage of the load. Even though this linearized version of the load model introduces an approximation error in the current, it satisfies the contraints related to the ratio of the active and reactive powers. The linearized load model is shown in Figure 3. As for the DC case, the linearized model is used during the initialization phase with the `homotopy` operator.

Dynamic load model

Even if the load model has inputs that can vary with respect to time, the model does not contain any dynamic effects. Dynamic effects are caused by inductive and capacitive elements that are able to store energy within electromagnetic fields. Models that can account for such dynamics are typically described in the time domain using an ordinary differential equation (ODE). For example the differential equation that describes the dynamics of a capacitor is

$$C\frac{dV_c(t)}{dt} = i(t), \tag{12}$$

where C is the capacity, $V_c(\cdot)$ is the voltage of the capacitor, and $i(\cdot)$ is the current flowing through it. The model represented by equation (12) requires a time domain simulation where sinusoidal functions are represented as time-varying signals. This requires significant computing. The dynamic phasorial representation (Stankovic et al., 1999; Stankovic and Aydin, 2000) allows a model represented by ODEs to be transformed into an approximated dynamic model, where the dynamics are described using phasors. The dynamic phasorial representation describes how the voltage and current phasors vary according to the differential equations derived from first principle models such as (12). The underlying assumption of dynamic phasors is to limit the analysis to the first of the harmonics. This limitation does not describe faster dynamics; however it represents slower ones with a simple model. The following code shows how the two representations can coexist in the same model.

```
  ...
equation
  omega = der(PhaseSystem.thetaRef(
              terminal.theta));
  // Electric charge
  q = C*{v[1], v[2]};
  if mode == Assumption.FixedZ_dynamic then
    // Use the dynamic phasorial
    // representation
    der(q) + omega*j(q) + R*v = i;
  else
    // Use quasi stationary
    // phasorial representation
    omega*j(q) + R*v = i;
  end if;
```

Generators

Generator models represent a source of power that is supplied to the grid. The generator is modeled as a load that generates a variable power that can have a phase shift with respect to the main reference angle.

Renewable sources

Renewable sources such as PV panels and wind turbines can be represented with a simplified AC model. In addition to the DC models, the AC models have a variable power factor that describes the phase shift between the voltage and current phasors. The models also have an efficiency factor that accounts for the power loss in the transformation between DC and AC. More detailed models can be created by coupling DC models and AC through an AC/DC converter.

Transformers

Transformers are devices that transfer energy between two circuits through electromagnetic induction. The package `Electrical.AC.Conversion` contains four different transformers:

- An idealized symmetric model that describes conversion losses using an efficiency factor.
- An idealized model that describes conversion between AC/DC using an efficiency factor.
- An asymmetric model that describes losses on the primary side.
- An asymmetric model that describes losses on primary and secondary sides as well as core and magnetization losses.

AC THREE PHASES BALANCED

Under the assumption that the electrical system and the loads are symmetric, it is possible to reduce a three-phase circuit to an equivalent circuit with a single-phase representation. This representation reduces the number of variables and keep the computational effort low. The price to pay is a less detailed description of the system that cannot account for unbalanced conditions that typically happen in real systems. The model in this package represents a simplification that can be used to perform faster simulation of large systems. The package `Electrical.AC.ThreePhasesBalanced` contains models that have been extended from the package `Electrical.AC.OnePhase`. The interfaces and nominal values of the voltages have been updated to represent three-phases systems. However, the mathematics remains the same.

AC THREE PHASES UNBALANCED

The AC three-phases unbalanced models account for a more detailed representation of electric networks. Diverse types of loads and different patterns of consumption cause voltages and currents to differ among the three phases. The unbalanced systems are modeled using components that are part of the `Electrical.AC.OnePhase` package. The models are connected together to represent sources, lines, and loads. The models can be used to represent three-phase systems with and without the neutral cable.

Connector

The connector for three-phase unbalanced systems is a vector that contains three `Electrical.AC.OnePhase` connectors. The number of connectors becomes four when the neutral cable is represented.

```
connector Terminal
```

```
  Electrical.AC.OnePhase.
    Interfaces.Terminal phase[3]
  "Vector of AC connectors, one for
   each phase";
end Terminal;
```

Ideal voltage source

The ideal voltage source consists of three different `AC.OnePhase` voltage sources, one for each phase. Given the phase-to-phase V_{RMS} voltage, the model parametrizes the RMS voltage of each phase as $V_{RMS}/\sqrt{3}$. The correspondent voltage phasors are shifted by 120°. By convention the first phase has an angle equal to zero, the second phase $-120°$, and the third phase $+120°$.

```
model FixedVoltage
  "Model of a fixed AC voltage 3 phases
  unbalanced source"
  parameter Voltage V = 480
      "RMS value line to line";
  parameter Frequency f = 60
      "Frequency of the source voltage";
  parameter Angle phi = 0
      "Phase shift of the source";
  Electrical.OnePhase.Sources.FixedVoltage
    Vphase[3](
      each f = f,
      each V = V/sqrt(3),
      phi = {phi,
             phi - angle120,
             phi + angle120})
protected
  constant Angle angle120 =
    2*Modelica.Constants.pi/3
    "Shift angle between the sources";
equation
  ...
end FixedVoltage;
```

Impedances and loads

The impedance and load models are the same as in the package `AC.OnePhase.Loads`. The main difference is that it is possible to select in which way they are connected. There are two configurations: star (also known as Y) and triangle (also known as D). When connected in the Y configuration, each load is connected to a single phase. When connected in the D configuration, the loads are connected between two phases.

Transformers

The transformer models reuse the models of the `AC.OnePhase.Conversion` package in different configurations. The various configurations depend on the possibility to connect the primary and the secondary sides of the transformer either with a Y or D configuration.

TRANSMISSION LINES

The package `Electrical.Transmission` leverages the abstraction level provided by the generalized connectors and contains models that can be used to represent transmission lines in the DC or AC single/multi-phases domains. The models ranges from simple resistance versions to more detailed models that account for the inductive and capacitive effects of the cables. The cables can be automatically sized, or the user can select between a collection of commercial cables.

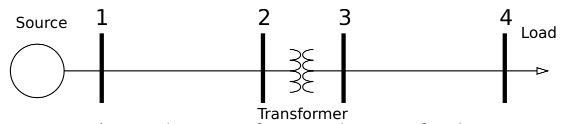

Figure 4: IEEE four-nodes test feeder.

VALIDATION

The models of the `Buildings.Electrical` package have been successfully validated to ensure their correctness and acccuracy. The package follows the same development guidelines as the Modelica Buildings library. Every component of the package is verified in a simulation example. The aim of the examples is to compare the model results to the analytical results if possible. Each simulation model has been included in the regression tests of the Modelica Buildings library. The regression tests enable users to check the correctness of the models during further development of the library. The next section reports the results of the validation of the AC three-phases unbalanced models against the IEEE four-nodes test feeder.

APPLICATIONS

This section contains two examples. The first describes the validation of the models contained in the `Buildings.Electrical` package against a standard test provided by IEEE. The second example focuses on the impact that the connection of PVs can have on the voltage of a residential district network.

IEEE four-nodes test feeder validation

This example shows a validation of the `Buildings.Electrical` models against the IEEE four-nodes test feeder validation procedure (Kersting, 2001). The tests that are part of the validation certify the capability to represent transformers of various configurations, full three-phase lines, and unbalanced loads. Figure 4 shows the structure of the four-nodes network. The voltage source is connected to the load through two lines and a transformer. The validation procedure consists of mutliple tests in which the type of the load and the type of the transformer vary. The test cases that have been successfully implemented using the models of the `Buildings.Electrical` package are listed in Table 1. Each row describes one validation tests. For example Gr Y - D Step Up indicates that the transformer has a grounded Y connection at the primary side, and a D connection at the secondary side.

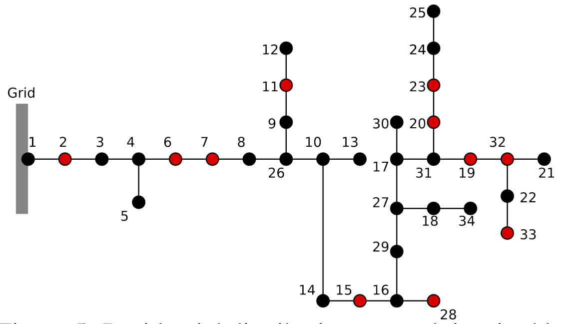

Figure 5: Residential distribution network inspired by the IEEE 34 nodes test feeder. The nodes in the grid are residential units. Red dots are residential units with PVs installed.

Step up indicates that the voltage at the secondary side is higher than the primary side. Each test listed in the table produces results that differ from the reference IEEE values by less than 0.05%, which is the threshold defined by IEEE to determine whether results should be accepted or not.

Table 1: IEEE four-nodes test feeder that has been successfully reproduced using the models of the `Buildings.Electrical` *package*

TRANSFORMER	LOAD
Gr Y - Gr Y Step Up	Balanced
Gr Y - D Step Up	Balanced
D - D Step Up	Balanced
Gr Y - Gr Y Step Down	Balanced
Gr Y - D Step Down	Balanced
D - D Step Down	Balanced
Gr Y - Gr Y Step Up	Unbalanced
Gr Y - D Step Up	Unbalanced
D - D Step Up	Unbalanced
Gr Y - Gr Y Step Down	Unbalanced
Gr Y - D Step Down	Unbalanced
D - D Step Down	Unbalanced

Impact of PVs on district voltage

This example investigates how the installation of PV panels in a district with residential homes can impact the voltages of the electric network. The district network considered in this example is shown in Figure 5. The network has the same topology as the IEEE 34-nodes test feeder (Kersting, 2001) but has been adapted in order to represent a residenatial district network. There are 34 nodes. The first node represents the voltage source, while the remaining 33 nodes are residential units. The nodes colored in red are residential units that have PVs. The residential district grid is modeled using a three-phase unbalanced system, and each residential unit is connected to a single phase. The residential units are connected to the single phases in a way that keeps the loads on each phase approximately the same. The PVs are connected to a single phase; the phase to which they are connected can be

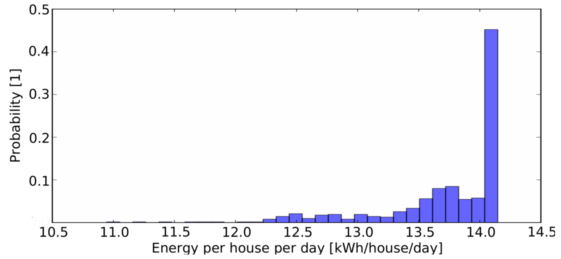

Figure 7: Probability distribution of the energy produced per day and house. The distribution is obtained assuming that the PVs are randomly connected to one of the three phases in the grid.

modified in order to analyze the impact they have on the voltage of the grid. Each PV has a local controller that disconnects the PV if the RMS voltage is outside of $\pm 10\%$ of 230 V. The controller disconnects the PV to protect the grid. However, when disconnected the PV produces no power. Both the residential units and the PV have been modeled using AC loads with a prescribed variable power consumption and production. The data series used for this example was taken from Labeeuw and Deconinck (2013). The model has been used to simulate a week during the month of June. Figure 6 shows the RMS voltage of each phase for every node in the grid. The RMS nominal voltage is 230 V, and the black lines in Figure 6 show the upper and lower limits within which the voltage of every node must remain. Figure 6 (left) shows the voltages of the grid nodes when the PVs have been connected uniformly in order to keep the network balanced. Figure 6 (center) shows the voltages of the grid nodes when all PVs have been connected to phase 1 without activating the voltage controller. The blue lines (voltages on phase 1 at every node) fall outside the limit and are generally higher than the nominal value. Figure 6 (right) shows the voltages of the grid nodes when all PVs have been connected to phase 1 and the local voltage controller is active. The blue lines (voltages on phase 1 at every node) remain within the limits but are still generally higher than the nominal value. Figure 6 compares the ideal case, in which the PVs are connected to keep the network balanced, and the worst case, in which all the PVs have been connected to phase 1. In a more realistic case, the PVs are installed without knowing how the other PVs have been connected. To represent such a case, the PVs have been connected randomly to one of the phases. Figure 7 show the probability that a house will produce a certain amount of energy per day given the random distribution of PV. In the current grid configuration, there is a high probability (45%) that even with a random connection of the PVs, the energy produced by each house is close to its maximum. The results depend on the type of cables used in the grid and the amount of power generated by the PVs. The higher the resistance of the cables, the higher will be the voltage overshoot and undershoot. The same applies for the power. The

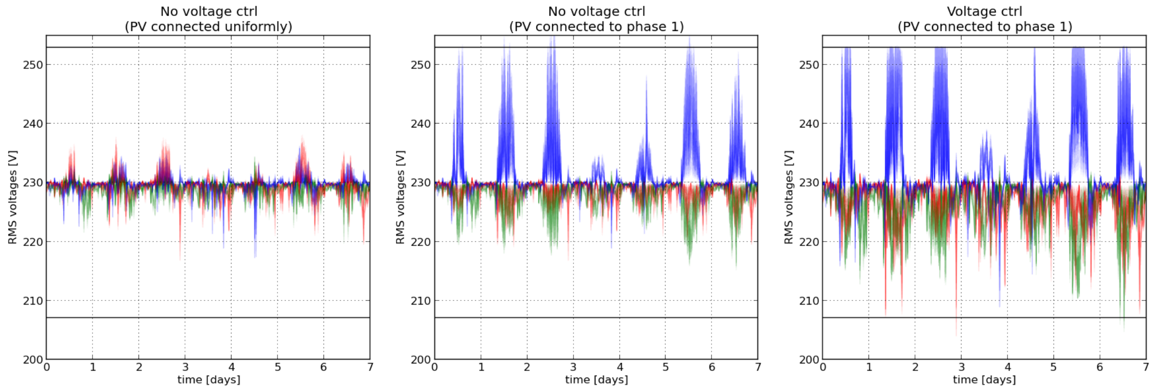

Figure 6: RMS voltages of the residential grid nodes. The blue lines are voltages at the nodes of phase 1, the red lines are voltages at the nodes of phase 2, and the green lines are voltages at the nodes of phase 3. The plot on the left shows the voltages when the PVs are connected in a balanced and uniform way (best case scenario). The plot in the middle shows the voltages when the voltage controller of the PVs is not active and all the PVs are connected to phase 1. The plot on the right shows the voltages when the voltage controller of the PVs is active and all the PVs are connected to phase 1.

higher the power generated by the PVs, the higher will be the voltage overshoot and undershoot. In this example, just 11 out of 33 residential units have PVs installed. If the number of PVs installed increases, there will be a higher probability that PVs are disconnected, and hence, less power will be produced.

CONCLUSION

The interaction between buildings and electrical systems is becoming more important if the fraction of renewable energy sources on the grid increases. This paper presents a package that extends the Modelica Buildings library by introducing models that represent the interaction between buildings and the electrical grid. The models were developed using a flexible approach that allows users to seamlessly switch between different electrical domains by leveraging abstract and standardized interfaces. The models have been implemented in a way that leads to more robust initialization. For some components, linearized versions are available to reduce the simulation time.

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