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METHOD AND CONTROL DEVICE FOR OPEN-LOOP AND CLOSED-LOOP CONTROL OF A POINTS HEATING SYSTEM

The present invention relates to a method and a control device for controlling and regulating a switch temperature of a switch heater, in particular as a function of weather, rail profile and position of the movable tongue rail by calculating and evaluating the real switch temperatures at functionally relevant points of the switch in winter on at least one switch segment between the switch tip and the switch end.

Track elements, in particular switches, of rail-bound vehicles such as railway vehicles (full tracks, side tracks, narrow-gage tracks) or trams are heated with switch heaters as required in order to prevent freezing of the movable parts or their blocking by penetrated snow and ice, especially in winter, and thus to ensure the operational safety. Known switch heaters are based upon systems with hot water vapor, gas heating, or electrical energy.

Switch heaters are used to melt snow between the rails of the switches in winter and to prevent the movable tongue rail from freezing in place onto the fixed stock rail and the slide chair plates as well as to prevent snow from being pressed together between the rails. For this purpose, heating devices with specific power of, for example, 330 W per meter of rail are arranged on the fixed stock rails of the switch, and in the case of corresponding weather the heating is put into operation by a weather station and thus the stock rail at the location of the switch temperature sensor of the switch is heated to a switch set temperature in on-off control with hysteresis.

The regulation of such switch heaters conventionally takes place by means of a switch temperature sensor on a central switch, which due to the function of the switch is arranged on the lower surface of the stock rail foot. In this case, there is the disadvantage that, during operation, the switch temperature corresponds to the switch set temperature only at the location of the switch temperature sensor and the remaining parts of the switch weather-dependent and from the position of the tongue rail, which can be abutting or not abutting the stock rail, both temperature deficits and temperature excesses can occur, which either lead to freezing in place and thus failure of the switch or to high (unnecessary) energy consumption.

The conventional switch heaters are currently switched on with 100 % specific power when heating is required and, after reaching the switch set temperature until a hysteresis of the real switch temperature is reached, are switched off and switched on again. The result during heating operation is power peaks between zero and the maximum value and significant temperature differences of the stock rails, tongue rails and slide chair plates of the right side and left side and over the length of the switch. A secure function of the switches in winter, in particular in the case of weather extremes, in wind, low ambient temperature and heavy snow, is not possible in automatic operation with the prior art.

Heating devices according to the prior art are arranged on the rail foot, for example, on the fixed stock rails of the left and right sides of the switch and are designed with a specific power of typically 330 W per meter over the entire length of the switch. The heat transfer to the tongue rails and slide chair plates of the switch takes place by heat conduction or heat radiation from the location of the stock rails provided with a heating device. During operation, different real switch temperatures are reached on the stock rails and the tongue rails on the left side and the right side of the switch as a function of the ambient conditions and the switch position, i.e., non-abutting or abutting tongue rail, and on the slide chair plates. At low ambient temperatures, weather extremes and/or wind, there are therefore considerable heating deficits, so that, despite heating, functionally relevant points of the switch do not reach zero degrees or do not reach positive switch temperatures, and thus the snow is not melted at these points. In this case, the snow is first pressed between the rails, i.e., between the tongue rail and the stock rail, during the setting of the switch, and the tongue rail can no longer reach the end position during setting or freezes in place and the switch can no longer be switched.

Using the analogy between an electrical flow field and a thermal flow field (cf. Tab. 1), heat generation processes, heat transfer processes and heat storage processes can be calculated with networks sufficiently known from electrical engineering. The non-linear processes occurring in heat networks require a computer-assisted iterative solution method [1].

Variable	Electrical	Thermal
Driving	Voltage difference $\Delta\varphi$	Temperature difference $\Delta\theta$

Flowing	Current I	Power P
Resistance	$R=\Delta \varphi/I$	$R_{th} = \Delta\theta / P$
Capacity	$c= dQ/\Delta\varphi$	$C_{th} = dW / d\theta$

Table 1: Analogy between thermal and electrical flow fields

In a heat network, heat sources, thermal resistances, heat capacities and fixed temperatures occur. They represent heat generation, heat transport, heat storage and thermal boundary conditions. The powers P generated in the conductors and the encapsulation are transmitted by radiation and convection to the environment and by heat conduction along the conductor track or the capsule, respectively. As a function of the thermal resistance R_{th} and the power P, an overtemperature $\Delta\theta$ results.

Heat transfer

In electrical systems, the power is transmitted by radiation, heat conduction and convection.

Radiation [2]

The radiation power exchanged between two bodies 1 and 2 is calculated with the Stefan-Boltzmann law with O_S as the surface of the radiating body and C_S = 5.67 W/m^2K^4 as the radiation coefficient of the black body.

$$P_s=C_s\,\varepsilon_{12}\,O_s\quad\left(\frac{T_1^4}{100}\quad-\quad\frac{T_2^4}{100}\right)$$

wherein the resulting emission number ε_{12} results for surrounding bodies (2 surrounds 1) from geometric considerations

$$\varepsilon_{12}=\frac{1}{\frac{1}{\varepsilon_1}+\frac{O_1}{O_2}\left(\frac{1}{\varepsilon_2}\right)-1}.$$

Heat conduction [2]

According to Fourier’s law of heat conduction, the transported thermal power P_L is, in the stationary state, linearly variable with the spatial change of the temperature if no additional heat source exists. The proportionality factor is referred to as thermal conductivity λ. The section length L and the cross-sectional area A significantly influence the transported thermal power. In the homogeneous one-dimensional heat flow field, the thermal power by conduction can be simplified as follows.

$$P_L = \frac{\lambda A \Delta \vartheta}{L}$$

<u>Convection [3], [4], [5]</u>

The thermal energy by convection is calculated from the relationships between the material properties of the cooling medium, the flow and the heat transmission to other media, arrangements and temperature ranges. To do this, dimensionless similarity numbers

Reynolds number	(abstracted from the forced convection)
Grashof number	(abstracted from the free convection)
Nusselt number	(abstracted from the heat transfer)
Prandtl number	(abstracted from the flow medium)

are formed with v as flow rate, v as viscosity, β as volume expansion coefficient, g as gravitational acceleration, c_p as a specific capacity and δ as density.

The relationship between the convective heat transfer coefficient K and the flow rate v is established using the *Nusselt*, *Frandtl* and *Reynolds numbers*:

$$\alpha_K = f(Nu)=f(Re,Gr,Pr)$$

With the *Newtonian* heat transfer law

$$P_K=\alpha_K O_K \Delta_\vartheta$$

the convection transmittable by convection is calculated.

The process can be iteratively calculated in the heat network in a temperature-dependent manner.

<u>Thermal powers</u>

As a result of the ohmic resistance, all the sections through which current flows are heated. Current heat losses occur due to the operating current, and capsule losses (hysteresis, induction and eddy current losses) occur due to induction in the capsule.

Current heat losses

If current I1 flows through operating means, a resistance counters the current flow due to the material property of the conductor. The converted power can be calculated with

$$P_{Lei} = I_I^2 R_{Lei}$$

and

$$R_{Lei} = k \frac{p1}{A} (1 + \alpha_T \Delta\vartheta)$$.

The resistance R_{lsi} is dependent on both the cross-sectional area A and the specific resistance of the conductor p, the section length l, the current type (current displacement factor k) [5] and the conductor overtemperature $\Delta\theta$[6]).

Heat capacity

The heat capacity of a conductor section goes into the calorimetric equation

$$Q_c = C\Delta\vartheta$$.

This can be converted to the power by derivation.

The heat capacity C results from

$$C = cm = c\delta V$$

with the volume V, the density δ and the specific heat capacity C.

The methods and control devices known from the prior art consequently sometimes have a very high technical installation and maintenance outlay, with simultaneously non-uniform and/or insufficient heating of essential functional parts of track elements. There is therefore a need to eliminate the disadvantages of the prior art without further increasing the technical effort.

US9353486B2, WO2018050141 A1 and WO2010115436A1 are cited as the prior art.

The object of the present invention is therefore to provide a method for controlling and regulating a switch heater and to provide a corresponding control device which overcome the disadvantages of the prior art and with which an additional outlay for sensors is avoided and the associated maintenance outlay is reduced.

The invention will be described in detail below. If object-related features are mentioned in the description of the method according to the invention, these relate in particular to the control device according to the invention. Likewise, method features cited in the description of the control device according to the invention relate to the method according to the invention.

The above-mentioned object is achieved in a first aspect of the present invention by a method for controlling and regulating a switch heater (1), wherein the switch heater (1) has at least one heating device (14) arranged on at least one switch (3), at least one switch temperature sensor (28) on the at least one switch (3), at least one energy distributor with at least one heating outlet per switch (3) and at least one control device for controlling and regulating the switch temperature, at least one terminal box arranged away from the switch (3) and having at least one switching device connected via lines to the heating devices (14) of the switch (3), and measuring means for the temporal detection of operating current, voltage and insulation resistance and means for limiting the maximum power, at least one communication means which is arranged in the terminal box and is connected to the control device, and at least one precipitation sensor for detecting the precipitation type and precipitation amount, which is connected to the control device, comprising the steps of:

a) defining at least one switch segment for the left side (5) of the at least one switch (3) and/or for the right side (6) of the at least one switch (3) having a specific length, wherein the switch segment of the at least one switch (3) has a stock rail (7), a tongue rail (8), a slide chair plate (9) and at least one heating device (14), and disassembling the at least one switch segment into individual sections, each with at least one first node, which corresponds to at least one functionally relevant point (19) of the switch segment of the at least one switch (3) in winter, wherein the functionally relevant point (19) has at least one evaluation point (37, 38, 39, 40, 41, 42, 43),

wherein the at least one switch segment is thermodynamically representative of the at least one switch (3),

wherein the at least one switch segment is arranged in the vicinity of the at least one switch temperature sensor (28),

b) forming a heat network (26) for the at least one switch segment for the left side (5) of the at least one switch (3) and/or forming a heat network (27) for the at least one switch segment for the right side (6) of the at least one switch (3), wherein the heat network (26, 27) has heat generating elements, heat transfer elements and heat accumulators (32), and assigning the respective at least first node (K) of the respective sections of the at least one switch segment to at least one evaluation point (37, 38, 39, 40, 41, 42, 43),

wherein all nodes (K) of the individual sections are connected via meshes to the heat network (26, 27) such that the difference of all signed temperatures is equal to zero,

c) calculating the temporal course of an optimum specific power (P_{op}) of the at least one switch segment and the respective optimum switch temperature at the at least one first node of the switch heater (1) on the at least one switch segment via a power balance according to a node set, and during operation, activating said optimum specific power at the associated heating device (14) by means of a product of real specific power of the heating device (14), which corresponds to the maximum specific power, and a power ratio, the power ratio corresponding variably between 25 % and 100 % of the real specific power,

d) detecting the temporal course of the real switch temperature at the at least one switch segment with the at least one switch temperature sensor (28) and correcting the calculated switch temperature at one of the at least first nodes of the at least one switch segment via convection heating power if calculated switch temperature is greater than the real switch temperature or radiant heating power of the heat network when calculated switch temperature is smaller than the real switch temperature,

e) calculating the switch end temperature at at least one second node of the at least one switch segment and comparing the calculated switch end temperature with a parameterized switch minimum temperature for this at least one second node,

wherein, if the switch minimum temperature of the switch (3) is not reached, a parameterizable switch set temperature is increased by a switch set temperature correction factor until the respective calculated switch end temperature of the switch (3) corresponds at least to the switch minimum temperature of the switch (3),

f) calculating the heating time for heating the at least one switch segment up to the parameterizable switch set temperature of the switch (3) and evaluating the calculated heating time at the parameterizable switch set temperature,

wherein the optimum specific power is increased in the event of a deficit and the optimum specific power is decreased in the event of a surplus,

g) calculating the heating time for heating the at least one switch segment up to the parameterizable switch minimum temperature of the switch (3) and evaluating the required specific power from maintenance power and melting power for the snow that has fallen up to that point with the specific power (P) at a parameterizable switch minimum temperature,

wherein in the event of a deficit, the optimum specific power is increased or a message “fallen snow quantity is too large and will not be melted” is generated.

With the method according to the invention, it is possible to heat a switch heater (1) as a function of existing or predetermined project-specific parameters or weather conditions by means of the heat network model according to the invention for one switch segment in each case for the left side (5) of a switch (3) and/or for the right side (6) of a switch (3), in particular for abutting ($_{an}$) and non-abutting ($_{ab}$) tongue rail (8), in the regions of the switch tip (16), the switch center (17) and the switch end (18). In this case, all specific power losses at the switch segments in the case of corresponding parameters can be determined the optimum switch temperatures (T_{op}) at nodes (K), each representing a functionally relevant point (19) of the switch segment in winter.

The method according to the invention is designed in principle to create the heat network model according to the invention solely with a switch segment for the left side (5) of a switch (3) or for the right side (6) of a switch (3). In this case, one of the two sides (5, 6) of the switch (3) is considered and it is assumed that the selected side (5, 6) of the switch (3) is the more positive of the two sides (5, 6) of the switch (3) with respect to the heating profile. A necessary reserve is thus included in the calculation.

However, it is particularly preferred if the heat network model according to the invention is created with one switch segment for the left side (5) of a switch (3) and one for the right side (6) of a switch (3), since in this way the potential of the present invention can be exploited even better. In the following, the particularly preferred variant is assumed without excluding the possibility of considering solely a switch segment for only one side.

Furthermore, the power of the individual heating devices (14) required during operation of the switch heater (1) can be calculated via the specific power of the length of a switch segment, the position of the switch, that is to say abutting or not abutting the tongue rail, can be determined by evaluating the switch temperature of the switch (3) at one switch segment on the left side (5) and one on the right side (6), and the power of the heating device (14) for the left side (5) and the right side (6) can be adapted in such a way that the functionally relevant points (19) of the switch (3) have the same switch temperatures over their entire length and thus a higher availability in winter over the entire operating temperature range is achieved during automatic operation of the switch heater (1) with maximally equal power of the heating device (14) compared to the prior art.

It is essential to the invention that the entire switch (3) is representatively modeled by at least one switch segment that includes both the left side (5) of the switch (3) and the right side (6) of the switch (3). In this way, the heat network (26, 27) according to the invention can be formed via a representative cross-section of the switch (3), with which the heating of the entire switch (3) is performed as uniformly as possible, and not only of individual regions or of one side of a switch as in the prior art.

In cold winters or in the case of extreme weather conditions, the present invention increases the availability of the switch heater, whereas in mild winters or weather periods without extreme weather conditions, significant energy savings can be realized and power peaks in the network can be avoided.

The method according to the invention is carried out as a function of existing or predetermined project-specific parameters or weather conditions, by means of the heat network model according to the invention for in each case one switch segment for abutting ($_{an}$) and non-abutting ($_{ab}$) tongue rail (8) in the regions of the switch tip (16), the switch center (17) and the switch end (18). All specific power losses at the switch segment are determined with corresponding parameters and the calculated optimum switch temperatures (T_{op}) are calculated at nodes (K), each representing a functionally relevant point (19) in winter of the switch segment.

The power of the heating devices (14) required during operation is calculated using the specific power (P) of the length of switch segments (l_{seg}) and the position of the switch (3), that is to say the position of the tongue rail (8) abutting ($_{an}$) or not abutting ($_{ab}$), is determined, preferably at the point of evaluation of the head tongue rail (41), by evaluating the calculated optimum switch temperature (T_{op}) on one switch segment on the left side (5) of the switch (3) and one on the right side (6) of the switch (3). The power of the heating device (14) for the left side (5) of the switch (3) and the right side (6) of the switch (3) is adapted in such a way that the functionally relevant points (19) at the switch tip (16), switch center (17) and switch end (18) switch segments of the left side (5) and the right side (6) have identical real switch temperatures (T_W) which correspond at least to the melting temperature of snow and/or the switch minimum temperature.

Over the entire winter (i.e., over the substantial period of use of the switch heater (1)), the time required during operation to heat the functionally relevant points (19) of the switch (3) from the “cold rail (T_K)” switch temperature of the switch (3) until a parameterizable minimum rail temperature (T_{min}) of the switch (3) is reached is monitored, taking into account the melting power (T_{Sm}) of snow and evaporation power of water. Measures are then initiated if this time is too large or the amount of snow (h_S) present during this time is not completely melted.

If, according to weather forecasts, the minimum rail temperature (T_{min}) of the switch (3) will not be reached or the amount of snow (h_S) will not be completely melted with the maximum specific power of the heating devices (14), the switch heater (1) according to the invention is put into operation by means of an additional heating request, “preheating,” with a second calculated rail set temperature ($T_{Soll-Vor}$) of the switch (3) so that the conditions are met when the heating request actually occurs. This allows action to be taken in advance instead of reacting only to a changing weather condition, as is the case in the prior art.

At the start of operation due to a “preheating” heating request, for example due to snowfall, a first pair of heating devices (14), for example the heating devices (14) on the stock rails (7), are preferably activated with an optimum specific heating power (P_{op}) and, when the rail set temperature (T_{Soll}) of the switch (3) is reached, a second pair of heating devices (14), for example on the tongue rails (8) or the slide chair plates (9), is activated. In this way, an increase in the connection power of the switch heater (1) according to the invention in comparison with the prior art is avoided by the first pair of heating devices (14) and the second pair of heating devices (14) being activated in a time-delayed manner or with a proportional specific power in that, in the case of on-off control, one pair of heating devices (14) is activated in the heating pauses of the other pair of heating devices (14) or group operation or power reduction takes place depending on the type of the heating device (14).

A switch segment is arranged in the vicinity of a switch temperature sensor (28) and the switch temperatures (T_W) of the switch (3) temporally detected therewith are verified with calculated optimum switch temperatures (T_{op}). In the event of possible switch temperature differences (ΔT_W), the calculated optimum switch temperatures (T_{op}) of the switch (3) are corrected via convection heat power (P_K) or radiation power (P_{St}).

The calculation takes place by means of the heat network model according to the invention for a switch segment using a microcontroller for a switch (3) or for a plurality of switches (3) of a switch heater (1) according to the invention, wherein the microcontroller is arranged directly next to the switch (3) and is connected to the control device in the distributor via communication means. The microcontroller contains switching devices or control devices for switching and controlling the heating devices (14) depending on the type of heating devices (14).

For the particular case in which there is still no heating request and there is a weather warning for the method, the method according to the invention further comprises step

h) calculating the specific melting power for the amount of snow calculated at the switch segment during the heating time from a reported snow height per time unit and calculating the specific maintenance power for maintaining the melting temperature at the switch segment and comparing the sum of these with the real specific power of the heating device (14) and, if the real specific power of the heating device (14) is lower, activating the switch heater (1) with a second switch set temperature, which is so large that the specific power of the heating device (14) is at least equal to the sum of specific melting power and maintenance power during operation.

In a development of the method according to the invention, the heat generating elements comprise the specific power of the at least one heating device (14) with a heat accumulator of the switch segment and a heat transfer by thermal radiation. Alternatively or additionally, and/or the heat transfer elements comprise thermal resistances at the switch (3) from the material properties, the geometric variables and the prevailing loads due to heat transfer and the environment on the at least one switch segment. This development advantageously results in a lower outlay for the calculation software.

In step f) of the method according to the invention, it can preferably

the heating time for the heating of the at least one switch segment is calculated from the sum of individual heating times for the at least one switch segment for heating it, for melting snow and for the evaporation of water on it, and/or

the heating time is increased by increasing the power ratio and/or switching from control operation to continuous operation and/or is decreased by decreasing the power ratio.

In the event of a high heating time, for example greater than 20 minutes, the function of the switch (3) in winter is endangered, not only in the 20 minutes but beyond it, because the snow forms a type of igloo and the switch heater (1) is not able to melt it subsequently.

In a preferred embodiment, the method according to the invention with active heating further comprises the steps of

i) calculating a melting power for fallen snow in a parameterizable time period and comparing this melting power with the difference between specific power and a calculated maintenance power, wherein in the event of a deficit in the specific power, the power is increased and/or continuous heating is started and/or a first warning message is issued,

and/or

j) comparing the calculated heating time with a parameterized maximum heating time, wherein in the event of a deficit in the specific power, the power is increased and/or continuous heating is started and/or a second warning message is issued,

and/or

k) calculating the snow height from the difference between the fallen snow height and the melted snow height per time unit and comparing the calculated snow height with a parameterizable maximum permissible snow height, wherein in the event of a deficit in the specific power, the power is increased and/or continuous heating is started and/or a third warning message is issued.

In the prior art, in the case of a heating request, heating is carried out in control operation and, in the event of a long heating time from low ambient temperatures, the amount of snow cannot be melted. As a result, the switch is snowed in and is no longer switchable. The advantage of the invention is the avoidance of the switch being snowed in in the operating temperature range.

Advantageously, the calculation of the heating time in step f) can comprise the substeps f1) calculating the dead time for the at least one switch segment from the temporal course of the switch temperature of the switch (3) at optimum or real specific power,

f2) calculating the time t_{A1} for heating the at least one switch segment from the switch temperature of the cold rail of the switch (3) and the melting temperature to the minimum switch temperature at at least one node,

f3) calculating the time t_{A2} to melt the amount of snow during step f2) from the difference of available specific power minus the power to maintain the switch minimum temperature of the at least one switch segment,

f4) calculating the time t_{A3} for melting the fallen snow during step f3) from the difference of available specific power minus the power for maintaining the minimum switch temperature of the at least one switch segment,

f5) calculating the time t_{A4} for heating the at least one switch segment from the difference between switch minimum temperature and the switch set temperature at the nodes with the switch temperature sensor of the switch (3),

f6) calculating the time t_{A5} for melting the fallen snow during step f5) from the difference of available specific power minus the power for maintaining the switch minimum temperature of the at least one switch segment.

The above-described calculation of the heating time in step f) enables monitoring and early reporting of functional deficits of the switch heater (1) instead of the occurrence of a malfunction.

A partial aspect of the method according to the invention relates to a determination of the ambient temperature operating limit ($G_{W\text{-}Tu}$) of the switch heater (1), comprising

- calculating the optional switch end temperatures at two specific nodes of the at least one switch segment which correspond to the head stock rail (20) and the head tongue rail (21) as functionally relevant points (19) of the at least one switch (3), wherein the calculated switch temperatures of the head stock rail and the head tongue rail are subtracted from the switch minimum temperature and the lowest one thereof corresponds to the operating limit ambient temperature.

An advantage according to the invention is that existing switch heaters can be adapted individually and optimally to the changed weather conditions.

Another partial aspect of the method according to the invention relates to a determination of the operating limit amount of snow ($G_{W\text{-}hs}$) of the switch heater (1), comprising

- calculating a specific maintenance power at switch minimum temperature T_{min} of the switch (3), plus a switch minimum temperature tolerance ΔT_{min}, at the stock rail foot, a melting power for the maximum amount of snow or the amount of snow detected up to that point, and an evaporation power for melt water, and comparing the sum thereof with the required specific power of the heating device (14) of the at least one switch segment, if the required specific power of the heating device is smaller than the sum of the maintenance power and the melting power and the evaporation power of the operating limit snow height is exceeded.

Another partial aspect of the method according to the invention relates to a project-specific dimensioning of the heating devices (14) and their required specific power, comprising

- calculating a specific power (P) of the heating device to reach a switch set temperature of the switch (3) at the location of the switch temperature sensor and a switch minimum temperature $T_{w\text{-}min}$ of the switch (3) at at least one head stock rail (20) and/or a head tongue rail (21) for the at least one switch segment by calculating the sum of heat conduction, radiation and convection into the surroundings, heat capacity and latent heat in the case of snow and sprinkling, with existing operating limits from minimum ambient temperature, rail profile, maximum wind speed and maximum snow height per hour, and

- increasing the required specific power if the calculated real specific power is less than the specific power that corresponds to the required melting power calculated in the heating time from minimum ambient temperature until a rail temperature of at least 0 °C is reached, for the amount of snow resulting from the product of heating time and snow height per hour, and the evaporation power of residual melt water and the required specific maintenance power for a rail temperature of 0 °C at the functionally relevant points of the at least one switch segment.

This results in the advantage that switch heaters (1) can be designed in accordance with the specific local environmental conditions, for example, differently in the mountains than on flat land.

In a preferred embodiment of the method according to the invention,

- during operation of the switch heater (1), an adjustment of the optimum specific power for the heating devices (14), which corresponds to the product of specific power and a power ratio of 25 % to 100 %, takes place via the respective switching devices for switching the heating devices (14) on and off by means of changing the duty cycle or the frequency or the pulse width or wave packet control or group operation,

and/or

- the power ratio is between 25 % and 100 %,

wherein, during operation of the switch heater (1), the specific power (P) of the left side (5) of the switch (3) and of the right side (6) of the switch (3) corresponds at most to the mean value and/or meridian of the specific power of the heating device (14),

and/or

- during operation of the switch heater (1), the calculated specific power P_{op} for the left side (5) of the switch (3) and the right side (6) of the switch (3) corresponds at most to the specific power (P) of the heating devices (14),

or a specific power difference for the left side (5) of the switch (3) or the right side (6) of the switch (3) is calculated from the difference of specific power (P) of the heating devices (14) minus calculated specific power (P_{op}) and, in the case of a positive specific power difference of the left side (5) of the switch (3) or the right side (6) of the switch (3), this specific power difference is made available to the respective other side of the switch (3) in addition to the specific power (P) of the heating device (14), so that a uniform temporal course of the rail temperatures of the switch (3) takes place on the left side (5) of the switch (3) and on the right side (6) of the switch (3) at the functionally relevant points (19) of the switch (3).

The above-mentioned object is achieved in a second aspect of the present invention by a control device for controlling and regulating a switch temperature of a switch heater (1) set up for carrying out the method according to any of claims 1 to 10, wherein the switch heater (1) has at least one heating device (14) arranged on at least one switch (3), at least one switch temperature sensor (28) on the at least one switch (3), and at least one energy distribution with at least one heating outlet per switch (3), the control device comprising:

- a CPU for calculating the switch temperatures of the switch (3) for at least one switch segment, which is connected to the control device via communication means,

- at least one terminal box which is arranged away from the switch (3) and has at least one switching device connected to the heating devices (14) of the switch (3) via lines, and measuring means for the temporal detection of operating current, voltage and insulation resistance and means for limiting the maximum power,

- at least one communication means which is arranged in the terminal box and is connected to the control device,

- at least one precipitation sensor for detecting the type and amount of precipitation, which is connected to the control device.

The control device according to the invention basically has the same advantages as the method according to the invention. In particular, the control device according to the invention provides the equipment required as a basis so that a switch segment, which includes both the left side (5) of the switch (3) and the right side (6) of the switch (3), represents a switch (3). In this way, the heat network (26, 27) according to the invention can be formed by a representative cross-section of the switch (3), with which the control device according to the invention performs the heating of the entire switch (3) as uniformly as possible.

Further objectives, features, advantages, and possible applications result from the following description of embodiments, which do not restrict the invention, with reference to the figures. In this case, all of the features described and/or illustrated form the subject matter of the invention, alone or in any combination, even independently of their summary in the claims or their back-references. In the drawings:

Fig. 0 shows a schematic plan view of a switch 3,

Fig. 1 shows a schematic sectional view of a switch segment having abutting tongue rail 10 and a non-abutting tongue rail 11,

Fig. 2 shows a temporal representation of the heating of a switch 3 with a switch heater according to the prior art,

Fig. 3 shows a schematic representation of a heat network 26, 27 according to the invention for a switch segment of the switch 3 consisting of the stock rail 7, tongue rail 8, slide chair plate 9 and heating device 14,

Fig. 4 shows a model for calculating the heating time with and/ without snow,

Fig. 5 shows an example of a program sequence plan for dimensioning the power of a heating device 14 as a function of project-specific operating limit values.

Fig. 6 shows an example of a program sequence plan for evaluating the function of the switch heater 1 as a function of the weather and thus verification of the availability of the switch 3 in winter with available power of the heating device 14, and

Fig. 7 shows an example of a program sequence plan (divided onto two pages for better clarity) for controlling and regulating a switch heater 1 according to the invention.

The invention will be described in detail below, wherein this description on the basis of specific embodiments does not limit the scope of protection of the claims.

In order to achieve the objectives already mentioned above with as few switch temperature sensors 28 as possible, the present invention consists, among other things, of performing the control and regulation as well as the dimensioning of the heating devices 14 and the determination of operating limits of existing switch heaters by evaluating the switch temperatures of the switch 3 at the functionally relevant points 19 of the switch 3 in winter for the switch heater 1 according to the invention, by means of calculation. According to the invention, this takes place via the heat network 26 of the left side 5 of the switch 3 and via the heat network 27 of the right side 6 of the switch 3 for at least one switch segment analogously to electrical flow fields, in that the control and regulation of the specific power of the heating device 14 of the switch heater 1 according to the invention takes place by evaluation via temperatures, calculated by means of heat network 26, 27, at the switch tip 34 switch segment, the switch center 35 switch segment, and the switch end 36 switch segment for the left side 5 of the switch 3 and the right side 6 of the switch 3, as a function of the switch position, that is to say for the tongue rail 10 abutting the stock rail and tongue rail 11 not abutting the stock rail, and as a function of the weather. The calculated optimum switch temperatures T_{op} of the switch 3 are compared with the temporal course, detected by a switch temperature sensor 28, of the real switch temperature T_W of the switch 3 from at least three measured values after the dead time of a heated rail has elapsed with the switch temperature sensor 28 of at least one switch 3. In the case of differences including a tolerance, which can arise, for example, from wind and solar radiation, this temporal course is corrected by convection losses and radiation power.

The solution according to the invention of the above-mentioned objects is achieved with a thermal modeling of the temperature course with division of the switch 3 into switch segments of the left side 5 and the right side 6 for the regions of switch tip 16, switch center 17 and switch end 18, which are characteristic for the evaluation of the function, taking into account the distance between the stock rail 7 and the tongue rail 8 due to the switch position, the rail profile, the type of the slide chair plate 9 with or without rollers, the type of precipitation and the amount of precipitation, the wind speed and the ambient temperature as well as possible thermal insulation or wind insulation. In this case, for the switch segments during operation with respective specific power of the heating device 14, the temporal course of the switch temperatures T_{op} of the switch 3 and the specific power losses are calculated with iterative solution methods and compared with the temporal course of the real switch temperatures T_W of the switch 3 detected via switch temperature sensors 28. In the case of differences, these are corrected taking into account a tolerance and are evaluated at functionally relevant points 19 of the switch 3, which are decisive for the function of the switch 3 in winter, so that during operation with determined weather-dependent optimum specific power, the heating device 14 is activated and at these points a minimum rail temperature T_{min} of the switch is reached. In this way, a uniform heating of the left side 5 of the switch 3 and the right side 6 of the switch 3 over the entire length of the switch 3 is achieved with minimal energy input and thus a high availability in winter is ensured.

When dimensioning, the required specific power of the heating device 14 is determined on the basis of local limit boundary ambient conditions. When determining operating limits of the switch heater 1 according to the invention, the switch end temperatures T_{wn} of the switch 3 are determined for existing switch heaters at functionally relevant points 19 at maximum limit values of the ambient conditions, at which the switch heater 1 in question still just works with the present specific power of the heating devices 14 during operation in winter. The operator can thus decide whether this operating limit is sufficient or not sufficient for its weather conditions.

For this purpose, for local, project-specific and characteristic unfavorable ambient conditions and all types of switches 3 with a corresponding respective rail profile, the required specific power of the heating device 14 is to be calculated with a program for, for example, a meter of length required for the heating devices 14 so that the switch heater 1 according to the invention functions successfully at these limit values in winter. That is to say that the switch 3 is kept free of snow and does not freeze in place. To evaluate the function, minimum rail temperatures of the switch 3 are defined at the functionally relevant points 19 of the switch 3, and the power losses given these conditions are calculated from thermal radiation 30, convection 3), heat conduction 33 and heat accumulator 32, taking into account the installation location of the heating device 14 and the position of the tongue rail 8 on the switch segments of the left side 5 of the switch 3 and the right side 6 of the switch 3 at the switch tip 16, switch center 17 and switch end 18. The sum of the power losses of each switch segment of the left side 5 of the switch 3 and/or the right side 6 of the switch 3, at which the minimum rail temperatures of the switch 3 are reached and the amount of snow is melted, corresponds to the required specific heating power for the respective side and the respective region of the switch 3. The heating devices have a length of up to 6 m. Therefore, the required specific heating power of the heating devices 14 is advantageously determined from the calculated maximum sum of the power loss of the switch segments of the left side 5 of the switch 3 and the right side 6 of the switch 3.

This determination takes place in such a way that, inter alia, for a specific rail profile, e.g., R54, minimum ambient temperatures and a maximum amount of snow are specified, and for functionally relevant points 19 of switch segments at switch tip 34, switch center 35 and switch end 36, the temporal course and the power losses of the heat conduction 33, the melting powers and the evaporation power P_V the optimum switch temperatures (T_{op}) are calculated and evaluated and it is recognized whether the entire amount of snow is melted. The following project-specific inputs are input, which represent the operating limit of the switch heater 1 according to the invention, i.e., at which the function of the switches 3 in winter is still to be ensured:

- switch profile, e.g., R54 with different dimensions and weight at switch tip 16, switch center 17 and switch end 18,
- rail set temperature T_{Soll} of the switch 3,
- minimum rail temperature T_{min} of the switch 3 and/or minimum ambient temperature T_{U-min},
- maximum amount of snow h_{S-max},
- maximum heating time of heated rail t_{An-max},
- maximum wind speed u_{max}.

The calculation of the final values of the power losses for the switch segment right side 6 of the switch 3 and the switch segment left side 5 of the switch 3 takes place at a switch end temperature of the switch 3 which corresponds at least to the absolute sum of the minimum rail temperature T_{min} of the switch 3 or the ambient temperature T_U and the lower switch set temperature (e.g., 7 °C minus 4 °C hysteresis results in 3 °C) of the minimum rail temperature of the switch 3 of the heated rails, for example stock rails 7 to the left and right (e.g., node K stock rail foot) and/or the parameterized minimum temperature at the functionally relevant points 19, for example +1 °C, wherein the sum of the power losses corresponds to the required specific power of the heating device 14 in watts per meter for a length of the heating device 14.

The required melting power for the amount of snow in one hour is determined from maximum amount of snow h_S, the horizontal surfaces of the switch segment and the average density of snow, e.g., of 100 kg/m^3, at air temperature less than 0 °C and 200 kg/m^3 at air temperature greater than 0 °C and an average specific melting heat of, for example, 335 kJ/kg. Snow begins to melt at 0 °C. The entire required specific power of the heating devices 14 results from the sum of the power losses at, for example, 0 °C and the melting power of the amount of snow which has fallen on the foot stock rail between the start of heating and reaching the minimum rail temperature T_{min} of the switch 3 of, for example, 0 °C. The amount of snow that has fallen is determined from the detected amount of snow and the time until reaching the minimum rail temperature T_{min} of the switch 3, which corresponds to the melting temperature of snow.

A successful function of the switch heater 1 according to the invention in winter should ensure a minimum rail temperature T_{min} of the switch 3 on the left side 5 of the switch 3 and the right side 6 of the switch 3 at the functionally relevant points 19 of the switch 3, wherein the minimum rail temperature T_{min} of the switch 3 corresponds to the melting temperature of ice and snow. These functionally relevant points are:

Stock rail head	(Index Ko-Ba)
Stock rail foot	(Index Fu-Ba)
Tongue rail head	(Index Ko-Zu)
Slide chair plate, outer	(Index GL-au)

on the left side 5 of the switch 3 and the right side 6 of the switch 3. The function of the switch heater 1 according to the invention is positively evaluated at these functionally relevant points 19 when the following conditions are met. The factor k takes into account temperature differences due to heat conduction between the points

$T_{Fu\text{-}Ba} > T_{Soll}$

$T_{Ko\text{-}Ba} >= T_{min}$

$T_{Fu\text{-}Zu} >= k \times T_{Soll}$

$T_{Ko\text{-}Zu} >= T_{min}$

$T_{GL\text{-}mi} >= k \times T_{Soll}$

$T_{Gl\text{-}au} >= T_{min}$

So that only one program is required for all the switch types, the evaluation takes place on typical switch segments for the left side 5 of the switch 3 and the right side 6 of the switch 3 over the regions of switch tip 35, switch center 36 and switch end 37. Parameterizable values for the left side 5 of the switch 3 and the right side 6 of the switch 3 of a switch segment are evaluated, for example:

$T_{Fu\text{-}Ba\text{-}min}$= switch set temperature * k (with k=1.5)

$T_{Ko\text{-}Ba\text{-}min}$= 0 °C

$T_{Fu\text{-}Zh\text{-}min}$= switch set temperature * k (with k=0.5)

$T_{Ko\text{-}Zu\text{-}min}$= 0 °C

$T_{GL\text{-}mi\text{-}min}$= switch set temperature * k (with k=0.5)

$T_{GL\text{-}au\text{-}min}$= 0 °C

Heating time $t_A <= t_{A\text{-}max}$

Melted snow during the heating time t_{Am} greater than amount of fallen snow h_s by evaluating the available specific power of the heating device 14 with the required maintenance power P_{erh} plus melting power for the amount of fallen snow.

The calculation method in conjunction with a control device for control and regulation can activate the following measures for ensuring the function of the switch 3 with minimal energy consumption over the entire operating range.

Setting the calculated optimum power of the heating device 14 via group control, wave packet control, pulse width modulation and frequency change as a function of the type of heating devices

Arrangement of additional heating devices 29 on the tongue rail 8 and/or the slide chair plates 9, which are activated and controlled temporally via the calculation model or via power distribution in such a way that, without increasing the connection power, the functionally relevant points 19 are heated uniformly over time and thus no temporal disadvantages of individual parts of the switch 3 occur.

In the case of deficits of the switch temperatures of the switch 3 predicted by means of calculation methods due to insufficiently available specific power of the heating device 14 on the non-abutting tongue rail 11, early warning message or message to switch the switch 3 if possible and/or preheating to a low rail set temperature of the switch 3, so that in the case of weather extremes due to, for example, heavy snowfall, the snow melts immediately.

For successful function of the switch heater 1 according to the invention, a uniform heating of the functionally relevant points 19 of the switch 3 of the abutting and non-abutting tongue rail 8 is required. Since the switch 3 is continuously switched as a function of the direction of travel during operation and no sensors for detecting the position of the tongue rail 8 are possible for the switch position, it is proposed to detect the position of the tongue rails 8 by evaluating the calculated temporal course of the switch temperature of the switch 3 on the left side 5 of the switch 3 and on the right side 6 of the switch 3

Heating device placement variants are:

Heating device 14 on the stock rails 7 and additional heating device 29 on the tongue rails 8 and, at the beginning of operation, heating the first rails with 100 % specific power of the heating device 14, wherein first rails can be stock rails 7 or tongue rail 8 or slide chair plates 9, and when the rail set temperature T_{Soll} of the switch 3 on the first rail is reached, reducing the respective specific power of the heating device 14 or 29 to maximum specific maintenance power P_{Erh} or lower or switching off the same and activating the additional heating device 29 on the tongue rail 7 or the slide chair plates 9 with the remaining specific power starting from this time and only in the heating pauses of the heating device 14 of the first rails, for example via group operation during cyclic cycle times in the case of electrical heating rods.

In the case of calculated deficits before a heating request, for example due to snow at the weather station, an additional heating regime “preheating” takes place, for example, in the case of possible weather extremes, via separate weather data from a local weather station or via a weather service such that a second rail set temperature of the switch 3 is calculated and the switch heater 1 according to the invention is switched into operation via preheating and is regulated to this second rail set temperature of the switch 3, wherein the second rail set temperature of the switch 3 is so large that, when the actual weather extreme effects occur, the snow is melted and the function of the switch 3 is ensured and, if the weather extreme does not occur, the preheating is terminated.

When additional heating elements 29 are placed on the stock rail 7 and the tongue rail 8 and/or the slide chair plates 9, the activation of the heating devices 14, during operation during the heating time, always takes place successively, i.e., initially activating the heating device 14 of the first rail with a power ratio of 100 % and after reaching the rail set temperature of the switch 3, activating the heating device 29 of the second rail in the heating pauses of the heating device 14 of the first rail, and in control operation, i.e., when both rails have rail set temperature of the switch 3, group operation or wave packet control or simultaneous heating operation of all heating devices 14, 29 takes place with reduced specific power or active heating time, wherein the sum of the specific power of the heating devices 14, 29 of the left side 5 of the switch 3 and the right side 6 of the switch 3 correspond maximally to the specific power of the heating device 14.

Evaluating snow melting via the power balance during the heating time in that the specific heating power is greater than or equal to the specific maintenance power plus the melting power for snow

Correction of the calculated temporal course of the rail set temperature of the switch 3 with the actually detected temporal course of the switch temperature of the switch 3 by means of switch temperature sensor 28 taking into account radiant heat from solar radiation and wind influence by convection.

A detailed description of the figures is given below.

Figure 0 schematically shows a switch 3 in plan view. The switch 3 is divided into switch tip 16, switch center 17 and switch end 18. Stock rails 7 and tongue rails 8 are shown. The assignment of the right side 6 of the switch 3 takes place from the tongue tip 16 in the viewing direction (reference sign 2) to the switch end 18. The non-abutting tongue rail 11 is shown on the left side 5 of the switch 3 and the abutting tongue rail 10 is shown on the right side 6 of the switch 3. A switch temperature sensor 28 is arranged on a stock rail 7, here on the left side 5 of the switch 3. A switch tip 34 switch segment, for example, is arranged in the region of the switch tip 16, a switch center 35 switch segment is arranged in the region of the switch center 17, and one switch end 36 switch segment is arranged in each case for left side 5 of the switch 3 and the right side 6 of the switch 3 in the region of the switch end 18. The switch temperature sensor 28 is located at the switch tip on the right side 6 of the switch 3 or on the left side 5 of the switch 3. Furthermore, the support catches 13 present in the support catch region are shown; they serve, on the side of the abutting tongue rail 10, to support the tongue rail 8 with respect to the stock rail 7 when the tongue rail 8 is traversed by the train.

Figure 1 shows a schematic sectional representation of the switch 3 from Figure 0 at the switch tip 34 switch segment with the left side 5 of the switch 3 and the right side 6 of the switch 3. On the left side 5 of the switch 3, the non-abutting tongue rail 11 is shown and on the right side 6 of the switch 3 the abutting tongue rail 12 is shown. The functionally relevant points 19 of the switch 3 in winter are shown on the left side 6 of the switch 3 by the evaluation points (37 to 43. As a result of the switch heater 1 according to the invention, these functionally relevant points 19, characterized by the evaluation points 37 to 43, are to be heated in winter when there are negative ambient temperatures such that the snow or ice located thereon is melted. The evaluation points 37 to 43 on the left side 5 and on the right side (69 of the switch of the switch 3 are the evaluation points foot stock rail 37, web stock rail 38, head stock rail 39, foot tongue rail 40, head tongue rail 41, center slide chair plate 42 and outer slide chair plate 43, which are each represented by nodes K of the heat network 26, 27 and correspond to the functionally relevant points 19 of the right side 6 of the switch 3 and the left side 5 of the switch 3. The switch temperature sensor 28 is arranged on the left stock rail 7 between two ties 24 and the real switch temperatures T_W detected therewith on the stock rail 7 left side 5 of the switch 3 can be compared with the calculated optimum switch temperatures at this functionally relevant point 19 with the calculated optimum switch temperatures $T_{W\text{-}op}$ and corrected in case of differences. During operation, the track of the switch 3 is changed continuously by displacing the tongue rails 8, in that, on the left side 5 of the switch 3 and the right side 6 of the switch 3, the tongue rail 8 is alternately abutting or not abutting the stock rail 7. Sensors for detecting the position of the tongue rail 8 are not present. The detection of the position of the tongue rails 8 abutting or not abutting the stock rails 7 takes place by evaluating the calculated optimum switch temperatures $T_{W\text{-}op}$ at respective evaluation points of the functionally relevant points 19, preferably at the evaluation point head tongue rail 41. The switch is heated with a heating device 14 on the stock rail foot.

In Figure 2, during operation of a switch heater according to the prior art at the point in time t_1 due to snowfall and a heating request “on” generated thereby, the temporal course of the real switch temperature $T_{W\text{-}Fu\text{-}Ba}$ on a rail on which the heating device 14 is arranged, for example on the foot stock rail, and the temporal course of the real switch temperature $T_{W\text{-}Au}$-GL on a rail not provided with the heating device 14, at a functionally relevant point of a switch, for example an external slide chair plate, is shown. After a dead time determined by the mass, the real switch temperature $T_{W\text{-}Fu\text{-}Ba}$ at the stock rail equipped with heating device rises. When the switch set temperature T_{Soll} at time t_6 is reached, the heater is switched off in the case of on-off control and after a low overshooting of the real switch temperature due to the mass of the rail up to time t_7, it cools until time t_8 and the heating current (I_N) is switched on again at this time. The time from t_1 to t_6 is referred to as heating time t_A and the time from t_6 to t_9 is referred to as control time. The slide chair plate located away from the heating device and not provided with the heating device 14 is heated only very slowly and at the time t_6 has a very low real switch temperature $T_{W\text{-}outer\text{-}GL}$, which is far below the set temperature.

At point in time t_6, the heating current for all heating devices of the switch is switched off by the parameterized hysteresis of, for example, 4 °C, so that the cooling also begins on the slide chair plate. The switch temperature difference ΔT_W at time t_6 between the foot stock rails and the slide chair plate is very large. This switch temperature difference ΔT_W is so great at an ambient temperature of, for example, -15 °C that the switch temperature on the outside of the slide chair plate is less than 0 °C even after a very long time and the switch can ice at this point and freeze in place. Figure 2 shows the temporal course of the heating current I_N in the case of heating request On, which is switched on and off during operation between zero and maximum heating current I_N as a function of the switch temperature at the foot of the stock rail and thus results in power peaks between zero and nominal current. At the points in time t_3, t_4 and t_5, the temperatures at the switch temperature sensor (28) are measured and for the evaluation or correction of the calculated optimum switch temperatures.

In Figure 3, a heat network 26 according to the invention for the left side 5 of the switch 3 and partially an analogous heat network 27 for the right side 6 of the switch 3 are shown for switch segment of the switch 3, in accordance with a sectional representation according to Figure 1, at any region of the switch 3, which are connected via the node K ambient temperature K_{TU}. Heating devices 14, 29 are arranged, for example, on the stock rail 7 on the inside of the stock rail foot. The heat network 26 for the left side 5 of the switch 3 and the heat network 27 for the right side 6 of the switch 3 are based on a sectional view along the slide chair plate 9 on the left side 5 of the switch 3 and the opposite slide chair plate 9 on the right side 6 of the switch 3 and the cross-section of the stock rail 7 and the tongue rail 8 on the left side 5 of the switch 3 and the stock rail 7 and tongue rail 8 on the right side 6 of the switch 3 at any switch region 4 of the switch 3 with heating device 29 symbols, thermal radiation 30 symbols, convection 31 symbols, heat conduction 33 symbols and heat accumulator 32 symbols between the functionally relevant points 19 of the switch 3, which are represented by node K.

In the heat network 26 of the left side 5 of the switch 3, a heat network, which is calculated using known rules, is present between the ambient temperature T_U, which is represented by node K ambient temperature K_{TU}, and functionally relevant points 19, which are also represented by node K. The nodes K for the functionally relevant points 19 of the switch 3 for the heat network 26 for the left side 5 of the switch 3 and for the heat network 27 for the right side 6 of the switch 3 are the same and correspond to the evaluation points 37 to 43, but the power losses of the abutting tongue rail 10 and the non-abutting tongue rail 11 are different. The following table shows the relationship between the functionally relevant points 19, the corresponding nodes K and the required switch temperature T_W that is calculated at the respective nodes K with the designation $T_{W\text{-}op}$ and evaluated in a separate program for the heat network 26 for the left side 5 of the switch 3. The heat network 27 for the right side 6 of the switch 3 is analogous to this and connected via the node K ambient temperature K_{TU}.

Functionally relevant point 19	*Node K*	*Required switch temperature T_W in degrees Celsius*
Ambient temperature	K_{TU}	Temperature range +10 °C to -20 °C
Left side stock rail foot	$K_{Fu\text{-}Ba\text{-}Li}$	Greater than k times the rail set temperature
Left side stock rail web	$K_{St\text{-}Ba\text{-}Li}$	Greater than or equal to rail minimum temperature
Left side stock rail head	$K_{Ko\text{-}Ba\text{-}Li}$	Greater than or equal to rail minimum temperature
Left side tongue rail head	$K_{Ko\text{-}Zu\text{-}Li}$	Greater than or equal to rail minimum temperature
Left side tongue rail web	$K_{St\text{-}Zu\text{-}Li}$	Greater than or equal to rail minimum temperature
Left side tongue rail foot	$K_{Fu\text{-}Zu\text{-}Li}$	Greater than or equal to rail minimum temperature
Left side slide chair plate, center	$K_{Gl\text{-}mi\text{-}Li}$	Greater than or equal to rail minimum temperature
Left side slide chair plate, outer	$K_{Gl\text{-}au\text{-}Li}$	Greater than or equal to rail minimum temperature

To calculate the switch temperatures of the switch 3 and the power losses, the switch segment is broken down into sections and each section is represented by a node K, which indicates the average switch temperature T_W of the assigned section. The size of the sections or the number of nodes K depend on the required reproduction accuracy. For all nodes K, the power losses and thermal resistances and heat capacities from the material properties, the geometric variables and the prevailing loads are calculated by heating current I_N and environment. A network is formed from the connection of the nodes K by resistors, capacitors and voltage sources, which network can be numerically solved with the aid of Kirchhoff's laws. If the power balance for a node K is created, Kirchhoff's first law (junction rule) applies.

$$P_S+P_K+P_L = P_{Lei} + P_c$$

According to Kirchhoff's second law (loop rule), it follows that along a closed loop, i.e., a mesh, the sum of the signed temperature differences is equal to zero. The calculation of the power losses and the heat transport processes takes place using a software program. The temperature-dependent thermal powers and thermal resistances are calculated according to the known calculation principles and the end temperature and the temporal course of the switch temperatures are calculated at the functionally relevant points 19 of the switch 3, which are represented by nodes K in the heat network 26, 27, and with inclusion of the heat capacities.

Figure 4 first shows the heating time t_A. When conditions are met for heating operation, for example in the case of snow, the heater is put into operation by means of a heating request signal from the control device and the heating devices 14 on the stock rails 7 are switched on and, after reaching the switch set temperature T_{Soll}, are regulated via on-off control with hysteresis and the parts of the switch 3 are thereby heated. The tongue rails 8 and slide chair plates 9 not provided with the heating device 14 are heated by heat conduction and radiation. The heating time t_A starts with activation of the heater and ends when the switch set temperature T_{Soll} at a switch temperature sensor 28 arranged under the foot on a stock rail 7 is reached. The duration of the heating time t_A is dependent on many factors and is intended to be calculated, monitored, and appropriate measures introduced if necessary to secure availability.

The calculation of the heating time t_A takes place for at least one switch segments for the left side 5 of the switch 3 and the right side 6 of the switch 3 in several steps, taking into account times in which the heating of the switch segment up to the switch minimum temperature T_{W-min} of the switch 3, snow melting, evaporation of water and then up to the switch set temperature T_{Soll} of the switch 3 takes place. Figure 4 shows the temporal course of the switch temperature $T_{W\text{-}Fu\text{-}Ba}$ of the switch 3 on the foot of a stock rail 7 and the switch temperature $T_{W\text{-}GL\text{-}au}$ on the outside of the switch 3 of the slide chair plate 9 on one side, for example, the left side 5 of the switch 3. The individual time segments are explained below. Due to inertia, a dead time t_T from t_1 to t_2 exists during operation. The dead time T_T is calculated.

The heating time t_A is the time until the melting temperature of snow is reached up to time $t_{2.1}$. From time t_2, the switch 3 is heated up to the melting temperature T_S, which is reached at time $t_{2.1}$. The calculation of the heating time t_A takes place via thermal resistance R_{th} and thermal capacity C_{th} determined with the heat network model and the power loss of the switch 3 based on the temporal course starting from the switch temperature of the cold rail T_K of the switch 3 up until the melting temperature T_S is reached, for example using the formulas

$$t_{A1} = \tau \ln \tau = R_{th}\, C_{th}$$

$$\tau = \left({}^{1}\!\Big/_{\left(1 - \left({}^{absT_u}\!\Big/_{\left(1 - \left(absT_K - T_u\right)\right)}\right)\right)}\right)$$

The time for melting the fallen or project-specific required amount of snow is composed of two partial times t_{A2} and t_{A3}. During time t_{A2}, the time to melt the amount of snow from time t_{A1} is calculated and during time t_{A3}, the amount of snow fallen during time t_{A2} is calculated. The melting power per hour is calculated from the amount of snow h_S and the horizontal surfaces of the switch segment and an average density of snow, e.g., of 100 kg/m^3 at air temperature of less than 0 °C and 200 kg/m^3 at air temperature of greater than 0 °C and an average specific melting heat of, for example, 335 kJ/kg. Snow begins to melt at 0 °C. The calculation of the specific power therefore takes place, for example, at a switch temperature of 0 °C on the stock rail 7, taking into account the required optimum specific power of the heating device 14 for maintaining the melting temperature of the stock rail 7, which corresponds to the sum of the power losses at this melting temperature.

The calculation of the entire heating time t_{A2} plus t_{ANH3} to melt the entire amount of snow from the heating time t_{A1} and the heating time t_{A2} takes place from the product of melting power per hour and the sum of time t_{ANH1} and time t_{ANH2} and dead time t_T.

After the snow is melted, the switch 3 is heated further. The heating time t_{A4} starts at time $t_{2.3}$ and ends when the rail set temperature T_{Soll} of the switch 3 is reached by the switch temperature sensor 28. The calculation of the heating time t_{A4} takes place via the thermal resistance R_{th} and thermal capacity C_{th} determined with the heat network model and the power loss on the basis of the temporal course, starting from the melting temperature until reaching the switch set temperature analogous to no. 1, with the corresponding absolute switch temperature from the difference of the switch set temperature and melting temperature.

During the heating time t_{A5}, the snow from the heating time t_{A4} is melted. The calculation takes place analogously to the heating time t_{A2} or t_{A3}.

The entire heating time t_A takes from time t_1 to t_7 and is determined and evaluated from the sum of dead time and heating times t_{A1} to t_{A5}.

Figure 5 shows a program sequence for the dimensioning of a switch heater 1 according to the invention with calculation of the required specific power of the heating devices 14 as a function of all possible project-specific input values, parameters and environmental conditions.

1st step Start

2nd step: Parameter input

The parameters are: Minimum ambient temperature T_{U-min}

Switch set temperature T_{Soll} of the switch 3

Switch minimum temperature T_{W-min} of the switch 3

Maximum wind speed v_{max},

Maximum amount of snow in cm per time unit h_{S-max},

Switch profile R

3rd step: Parameterizing functionally relevant points

Functionally relevant points (19) are, for example,

Switch temperature of foot stock rail abutting and non-abutting, left side ($T_{Fu\text{-}Ba\text{-}an}$, $T_{Fu\text{-}Ba\text{-}ab}$)

Switch temperature of head stock rail abutting and non-abutting ($T_{Ko\text{-}Ba\text{-}an}$, $T_{Ko\text{-}Ba\text{-}ab}$)

Switch temperature of head tongue rail abutting and non-abutting ($T_{Ko\text{-}Zu\text{-}an}$, $T_{Ko\text{-}Zu\text{-}ab}$)

Switch temperature of slide chair on the outside abutting and non-abutting ($T_{GL\text{-}au\text{-}an}$, $T_{GL\text{-}au\text{-}ab}$)

Specific amount of snow abutting and non-abutting ($h_{S\text{-}an}$, $h_{S\text{-}ab}$)

at the switch tip 16, switch center 17 and switch end 18 of each switch segment. The heating devices 14 are to be attached, for example, to the stock rails 7; the installation of the heating devices 14 takes place on the rail foot; the switch 3 is to be equipped without heating insulation or wind insulation. Each functionally relevant point 19 is represented by a node K with location information not designated in greater detail here.

4th step: Calculating the switch temperatures and specific power losses ΣP_{V1} for 1st switch segment by means of heat network model from the material properties, the geometric variables and the input parameters and outputting of the total power loss of the switch segment and the switch temperatures for the functionally relevant points 19 on the abutting and non-abutting side of the switch segment

5th step: Calculating specific power losses ΣP_{Vn} for further switch segments analogously to 4th step

6th step: The required specific heating power P_{erf} results from the sum of the power losses ΣP_{Vn} of each switch segment.

7th step: Checking, with the calculated specific power at the location of the switch temperature sensor, abutting or non-abutting side, the switch set temperature reached? If “Yes,” continue to step 10, if “No,” continue to step 8.

8th step: Evaluation

The calculated switch end temperature of the switch 3 at the foot stock rail on the abutting side $T_{W\text{-}Fu\text{-}Ba\text{-}an}$ or not abutting side $T_{W\text{-}Fu\text{-}Ba\text{-}ab}$ is less than the switch set temperature T_{Soll} of the switch 3, result is switch end temperature of the switch 3 at the stock rail foot ($T_{W\text{-}Fu\text{-}Ba}$) is too low, the switch set temperature T_{Soll} of the switch 3 is not reached, continue with step 9.

9th step: Increasing the specific power P of the heating device 14 by a power addition p of, for example, 10 watts per meter and repetition of the calculation according to step 4.

10th step: Checking, is the calculated switch end temperature of the switch 3 at the head stock rail abutting side $T_{W\text{-}Ko\text{-}Ba\text{-}an}$ or not abutting side $T_{W\text{-}Ko\text{-}Ba\text{-}ab}$ less than the switch minimum temperature $T_{W\text{-}Min}$ of the switch 3? If, for example, the switch temperature of the switch 3 at the head stock rail $T_{op\text{-}Ko\text{-}Ba}$ of the abutting or non-abutting side is less than the parameterized switch minimum temperature $T_{W\text{-}Min}$, continue with step 9. If the calculated switch temperature of the switch 3 on side abutting and not abutting the head stock rail ($T_{op\text{-}Ko\text{-}Ba\text{-}an}$, $T_{op\text{-}Ko\text{-}Ba\text{-}ab}$) greater than or equal to the minimum rail temperature of the switch 3, continue to step 11.

11th step: Checking, is the calculated switch end temperature of the switch 3 at the head tongue rail 21 abutting side $T_{op\text{-}Ko\text{-}Zu\text{-}an}$ or non-abutting side $T_{W\text{-}Ko\text{-}Zu\text{-}ab}$ less than the switch minimum temperature $T_{W\text{-}Min}$ of the switch 3? If “YES,” continue to step 9, if “No,” continue to step 12.

12th step: Checking, is the calculated switch end temperature of the switch 3at outer slide chair plate abutting side $T_{W\text{-}GL\text{-}au\ \text{-}an}$ or not abutting side $T_{W\text{-}GL\text{-}au\text{-}ab}$ less than the switch minimum temperature $T_{W\text{-}Min}$ of the switch 3? If “YES,” continue to step 9, if “No,” continue to step 13.

13th step: Amount of snow is melted

Checking, is the maximum amount of snow melted or not by comparison of the sum of calculated specific maintenance power P_{Erh} at switch minimum temperature $T_{W\text{-}Min}$ of the switch 3 and specific melting power P_{Sm} for the maximum amount of snow h_S with the calculated specific power (P_{op})? If the calculated specific power P_{op} is greater than or equal to the sum of the maintenance power P_{Erh} and melting power P_{Sm}, continue to step 14, otherwise continue to step 9.

14th step: Output of the required specific power of heating device P for a switch heater 1, which ensures the availability of the switch in winter with low energy consumption in automatic operation up to the input parameters.

Figure 6 shows the program sequence for proving the function of the switch heater 1 according to the invention as a function of the minimum ambient temperature T_u, the available specific power of the heating device P, the switch set temperature T_{Soll} of the switch 3 at maximum wind speed v_{max} for the rail profile R of the switch 3 as well as a possible maximum amount of snow per hour $h_{S\text{-}max}$ and the location of the heating devices 14 on the stock rail 7 and/or tongue rail 8 and/or slide chair plate 9. With such a method, the limit of the function of the switch heater 1 according to the invention and thus the availability of the switch 3 in winter for a switch heater 1 designed as standard can be determined and evaluated, including during operation with current air temperature, amount of snow per hour and wind speed v. In Figure 6, the availability of the switch 3 in winter as a function of the switch temperatures of the switch 3 at the functionally relevant points 19 of the non-abutting (right) side 6 of the switch 3 and the abutting side 5 of the switch 3 head stock rails, head tongue rail and outer slide chair plate are determined by comparison with the switch minimum temperature $T_{W\text{-}Min}$ of the switch 3, and the snow melting function during the heating time t_{ANH} is determined by comparison of the specific power of the heating device P with the required specific power Perf, which results from the sum of maintenance power PErh and the power of melting heat PSm, and the possible deficits are determined or the function of the switch heater 1 as a function of the weather is confirmed.

The steps for the evaluation of an existing switch heater 1 at a minimum ambient temperature $T_{U\text{-}min}$, maximum amount of snow per hour hS and max. wind speed V_{max} are shown below.

Step 1: Start of program

Step 2: Input of minimum expected ambient temperature T_{Umin}, specific power of heating device P, switch set temperature T_{Soll}, maximum wind speed V_{max}, rail profile R of the switch 3, maximum amount of snow per hour hs, and location of the heating devices 14 on the stock rail 7 and/or tongue rail 8 and/or slide chair plate 9, minimum point temperature T_{min}.

Step 3: The optimum specific power of the heating device on the abutting (left) side P_{op-Li} and the optimum specific power of the heating device on the non-abutting (right) side P_{op-Re} results from the specific power of heating device P on the respective stock rails 7, tongue rails 8 or slide chair plates 9.

Step 4: For abutting (left) side 5 of the switch 3 and non-abutting (right) side 6 of the switch 3, one switch segment is formed in each case with one heat network model, wherein the tongue rail 8 is shown, for example, abutting for the abutting (left) side 5 of the switch 3 and the tongue rail 8 is shown non-abutting for the non-abutting (right) side 6 of the switch 3, and the calculation of the switch temperature T of the switch 3 at time t6 of the heating time T_A when the switch set temperature T_{Soll} of the switch 3 is reached takes place by calculating the power losses of radiation P_{St}, convection P_K, heat conduction P_L, melting heat P_{Sm} and heat storage P_C at specific power of heating device P, and by calculating the maintenance power at time t2.1 of the heating time T_A when the switch minimum temperature T_{min} of the switch 3 is reached.

Step 5: Output of the switch temperatures T and the sum of the power losses of abutting (left) side ΣP_{V-Li} and the sum of the power losses of non-abutting (right) side ΣP_{V-Re}

Step 6: Checking, is the calculated optimum switch temperature T of the switch 3 at the switch temperature sensor 28, for example, on the (left) side abutting the foot stock rail, abutting, and non-abutting (right) side 6, greater than the switch set temperature T_{Soll} of the switch 3, taking into account a factor k, for example, of 1.5? If “YES” continue to step 7, if “NO” continue to step 13.

Step 7: Checking, is the calculated optimum switch temperature T of the switch 3 abutting the head tongue rail (left side 5) and not abutting (right side 6) greater than or equal to the switch minimum temperature of the switch 3? If “YES” continue to step 8, if “NO” continue to step 13.

Step 8: Checking, is the calculated optimum switch temperature T of the switch 3 abutting the outer slide chair plate (left side 5) and not abutting (right side 6) greater than or equal to the switch minimum temperature of the switch 3? If “YES” continue to step 14, if “NO” continue to step 13.

Step 9: Determining the required specific power from the sum of maintenance power to maintain the switch minimum temperature of the switch 3 on the stock rail 7 and the melting power of the abutting (left) side P_{Sm-Li} and melting power of the non-abutting (right) side P_{Sm-Li} for melting the previously entire amount of snow, which results from detected amount of snow per time unit and time t2.3 of the heating time t_A.

Step 10: Checking, is the required specific power of the abutting (left) side P_{erf-Li} or the required specific power of the non-abutting (right) side P_{erf-Re} less than or equal to the specific power of heating device P? If “YES” continue to step 11, if “NO” continue to step 12.

Step 11: The fallen amount of snow is smaller than or equal to the melted amount of snow. The fallen snow is melted during the heating time.

Step 12: The fallen amount of snow is greater than the melted amount of snow. The fallen snow is not melted during the heating time.

Step 13: Output of deficit for abutting and non-abutting sides with text not specified in detail here.

Step 14: Output of the operating limit values with, for example, minimum values from switch temperatures of the switch 3 abutting (left) sides 5 and non-abutting (right) sides 6 head stock rails and head tongue rails, as well as melted amount of snow.

The same program can be integrated into the control and regulation in that, in instead of minimum values or maximum values, the current ambient temperature, wind speed and amount of snow are read in and suitable corrective measures or warning messages are activated. A suitable correction is, for example, to arrange additional heating devices on the slide chair plates 9 or tongue rails 8 and to activate the heating devices on these first, so that the possible problems are solved due to the low mass. Figure 7 correspond the program sequence plan for the control and regulation of a switch heater 1 according to the invention for a switch 3 with rail profile R54 by calculating and evaluating the temporal course of the switch temperatures of the switch 3, the switch end temperature of the switch 3 and the heating time t_A at the points 19, which are functionally relevant in winter in ice and snow, of a switch segment having a specific length l_{seg} for a left side and a right side at a point (not designated in greater detail) of the switch 3. The nodes K shown in Figure 7 correspond to the foot stock rail evaluation point 37, the head tongue rail 41 evaluation point, the foot tongue rail evaluation point 40, the center slide chair plate evaluation point 42 and the outer slide chair plate evaluation point 43 for the left side 5 of the switch 3 and the right side 6 of the switch 3 shown in Figure 1 over the length of the switch 3, which are characterized by switch regions 4 of switch tip 16, switch center 17 and switch end 18, wherein each switch region is represented by a switch segment left side 5 of the switch 3 and an opposite switch segment on the right side 6 of the switch 3. The division of the switch 3 into left side 5 and right side 6 takes place, for example, from the switch tip 16 in the viewing direction toward the switch end 18.

Step 1. Input

By way of example, the input takes place for a switch 3 with heating device 14 with specific power P of 330 watts per meter on the stock rails 7. The switch set temperature of the switch 3 is 7 °C, the switch minimum temperature $T_{W\text{-}min}$ of the switch 3 for the melting of snow at the switch 3 is parameterized at +/-0 °C and a minimum power ratio L_V of 40 %, so that the optimum specific power P_{op} of the heating device 14 is set at 330 W/m multiplied by 40 % equals 132 W/m at the start of operation. The location of the switch temperature sensor 28 w_T is, for example, the left side 5 of the switch 3. The operating range values are established by the operator of the switch 3 with rail profile R54 for an ambient temperature to -20 °C at a maximum wind speed of up to 0.8 m/s and a maximum amount of snow of up to 5 cm/h. Up to these operating values, the function of the switch 3 by the switch heater 1 according to the invention should be ensured by ensuring the required switch minimum temperature $T_{W\text{-}min}$ at the functionally relevant points 19 and corresponding optimum specific power P_{op} to melt the amount of snow h_S.

Step 2. Selection of the switch segment and calculating the specific power of the switch segment left side and right side with 330 W/m * 40 % = 132 W/m.

Step 3. Reading in switch segment 1 left side and right side of the current ambient temperature, switch temperature, amount of snow, precipitation type, precipitation quantity and wind speed.

Step 4. Calculating the switch temperatures of the switch 3 and power losses in the power equilibrium (stationary end value) at 6 node points in the heat network model 26 for the left side 5 of the switch 3 and in the heat network model 27 of the right side 6 of the switch 3. In addition, calculating the maintenance power at time $t_{2.1}$. (required power to maintain temperature of 0 °C).

Step 5. Checking whether heating request due to snowfall or low ambient temperatures exists. If yes, continue with step 6, if no, continue with step 2.

Step 6. Checking whether the current time is greater than the dead time. If yes, continue with step 7, if no, continue with step 8

Step 7. When the dead time has elapsed, measuring the switch temperature of the switch 3 by means of a switch temperature sensor and comparing with calculated switch temperature at the respective node K and calculating the switch end temperature via time constant or model parameters.

Step 8. Checking whether the switch temperature of the switch 3 of the head tongue rail left side is greater than the switch temperature of the switch 3 on the head tongue rail right side. If “Yes”, the left side is the abutting tongue rail 8 (assuming switch temperature of head tongue rail is higher, so that it is detected whether the switch has been switched).

Step 9. Checking whether the left side or the right side is the location of the switch temperature sensor. In the example, the left side is the location of the switch temperature sensor 28. On the side with the switch temperature sensor 28 continue with step 10, on the side without a switch temperature sensor continue with step 12. An equipping of both sides with switch temperature sensors is possible.

Step 10. Assigning switch temperature left side is abutting and switch temperature right side is non-abutting

Step 11. Checking whether the calculated switch temperature of the switch 3 foot stock rail abutting is equal to the real switch temperature of the switch 3 foot stock rail, taking into account a switch temperature tolerance; if "No" continue to step 19, if "Yes" continue to step 12.

Step 12. Checking whether calculated switch temperature of the switch 3 foot stock rail is greater than the switch set temperature of the switch 3 plus a constant and minus the ambient temperature. If "No," increasing the power ratio L_V by the factor x (in the example 10 %) and continuing to step 2, if "Yes" continue to step 13.

Step 13. Checking whether maintenance power plus the power of melting heat P_{Sm} is less than or equal to the optimum power at time $t_{2.3}$. If "No," increasing the power ratio L_V by the factor x (in the example 10 %) and continuing to step 2, if "Yes" continue to step 14.

Step 14. Checking whether the heating time of the foot of the stock rail $t_{A\text{-}Fu\text{-}Ba}$ is less than or equal to the maximum heating time $t_{A\text{-}max}$. If "No," increasing the power ratio L_V by the factor x (in the example 10 %) and continuing to step 2, if "Yes" continue to step 15.

Step 15. Checking whether the temperature of the head of the tongue rail $T_{Ko\text{-}Zu}$ is greater than or equal to the switch minimum temperature T_{min}. If "No," increasing the switch set temperature T_{Soll} by the factor y (in the example 0.5 K) and continuing to step 2, if "Yes" continue to step 16.

Step 16. Checking whether the temperature at the foot of the tongue rail T_{Fu-Zu} is greater than or equal to the switch minimum temperature T_{min}. If “No,” increasing the switch set temperature T_{Soll} by the factor y (in the example 0.5 K) and continuing to step 2, if “Yes” continue to step 17.

Step 17. Checking whether the temperature in the center of the slide chair T_{GL-mi} is greater than or equal to the switch minimum temperature T_{min}. If “No,” increasing the switch set temperature T_{Soll} by the factor y (in the example 0.5 K) and continuing to step 2, if “Yes” continue to step 18.

Step 18. Checking whether the temperature at the outer edge of the slide chair T_{GL-au} is greater than or equal to the switch minimum temperature T_{min}. If “No,” increasing the switch set temperature T_{Soll} by the factor y (in the example 0.5 K) and continuing to step 2, if “Yes” continue to step 20.

Step 19. Correction of the calculation from step 4 with the aid of a correction factor for adapting the convection losses or radiation power. If the calculated switch temperature of the switch 3 abutting the foot stock rail is less than the real switch temperature of the switch 3 foot stock rail, taking into account a switch temperature tolerance, the heat transfer coefficient of convection α is reduced by the factor n (in Example 1) and continue to step 4. If the calculated switch temperature of the switch 3 abutting the foot stock rail is greater than the real switch temperature of the switch 3 foot stock rail, taking into account a switch temperature tolerance, the wind speed V is increased by the factor n (in Example 1) and continue to step 4.

Step 20. Output of the optimum power P_{op-Li} for the left side of the switch 3 and the optimum power P_{op-Re} for the right side of the switch 3 for the following cycle time t_z.

In summary, it should be noted that the present invention specifies a method in which the heat network model according to the invention changes the switch set temperature and/or the specific power at least one heating device 14 via a comparison of the calculated switch temperatures with parameterized switch minimum temperatures.

Furthermore, the heat network model according to the invention verifies the calculated switch temperatures by comparing with switch temperatures detected via a switch temperature sensor 28 by means of correcting the convection power and/or the radiation power.

In addition, the heat network model according to the invention generates a warning message in the control device warning of exceeding the operating limit for a control system and on site.

Finally, the heat network according to the invention determines the heating time before and during operation and activates an additional preheating heating routine via the control device if, as a function of the predicted ambient conditions from a weather service, the maximum amount of snow during the heating time is exceeded and/or the amount of snow is not melted.

Reference signs

1	Switch heater
2	Switch viewing direction
3	Switch
4	Switch region
5	Left side
6	Right side
7	Stock rail
8	Tongue rail
9	Slide chair plate
10	Abutting tongue rail
11	Non-abutting tongue rail
12	Abutting region
13	Support catch
14	Heating device
16	Switch tip
17	Switch center
18	Switch end
19	Functionally relevant point
20	Head stock rail
21	Head tongue rail

22	Center slide chair plate
23	Outer slide chair plate
24	Tie
25	Tie distance
26	Heat network, left side
27	Heat network, right side
28	Switch temperature sensor
29	Heating device symbol
30	Thermal radiation symbol
31	Convection symbol
32	Heat accumulator symbol
33	Thermal conduction symbol
34	Switch tip switch segment
35	Switch center switch segment
36	Switch end switch segment
37	Foot stock rail evaluation point
38	Web stock rail evaluation point
39	Head stock rail evaluation point
40	Foot tongue rail evaluation point
41	Head tongue rail evaluation point
42	Center slide chair plate evaluation

43	External slide chair plate evaluation point
P_{St}	Power of radiant heat
P_L	Power of heat conduction
P_K	Power of convection heat
P_{op}	Optimum specific power
P	Real specific power of heating device
P_{erf}	Specific power required
ξ_L	Length correction factor
P_C	Power of heat capacity
P_V	Power of evaporation heat
P_{Sm}	Power of melting heat
P_{Erh}	Maintenance power
R	Switch profile
T_U	Ambient temperature
T_{U-min}	Minimum ambient temperature
T_W	Real switch temperature
ΔT_W	Real switch temperature difference
T_{min}	Switch minimum temperature
T_{op}	Optimum switch temperature
T_{Soll}	Switch set temperature
$T_{Soll-Vor}$	Second switch set temperature

T_S	Melting temperature
T_V	Evaporation temperature
T_K	Cold rail switch temperature
NI	Precipitation type
L_V	Power ratio
L_{sp}	Specific length of heating device
K	Node (K)
I_N	Heating current
t_A	Heating time
t_E	Switch-on time
t_z	Time cycle
k	Factor
α	Heat transfer coefficient, convection

Examples of designation of nodes (K) and temperatures

$K_{Fu\text{-}Ba\text{-}Li}$	Node (K) of foot stock rail, left side
$K_{Ko\text{-}Ba\text{-}an}$	Node (K) of head stock rail, abutting tongue rail
$T_{Ko\text{-}Ba}$	Switch temperature - head stock rail
$T_{Ko\text{-}Ba\text{-}Li}$	Switch temperature - head stock rail, left side of the switch
$T_{Ko\text{-}Zu}$	Switch temperature - head tongue rail
$T_{Gl\text{-}mi}$	Switch temperature - center slide chair plate
$T_{GL\text{-}au}$	Switch temperature - outer slide chair plate

t_T	Dead time
t_A	Heating time
t_{max}	Maximum heating time
h_S	Amount of snow per hour
v	Wind speed
v_{max}	Maximum wind speed
n	Cycle factor
t_n	Time
t_z	Cycle time
y	Switch set temperature correction factor
W_T	Location of switch temperature sensor

Indices:

an	Abutting
ab	Non-abutting
Re	Right side
Li	Left side
Ba	Stock rail
Zu	Tongue rail
GL	Slide chair plate
Ko	Head
Fu	Foot

St	Rail web
au	Outer
mi	Center
op	Optimum
w	Real

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PATENTKRAV

1. Fremgangsmåde til styring og regulering af en sporskifteopvarmning (1), hvor sporskifteopvarmningen (1) indeholder mindst én varmeanordning (14), der er anbragt på mindst ét sporskifte (3), mindst én sporskiftetemperatursensor (28) på det i det mindste ene sporskifte (3), mindst én energifordeling med mindst ét varmeudtag pr. sporskifte (3) og mindst én styreanordning til styring og regulering af sporskiftetemperaturen, mindst én tilslutningsdåse, som er anbragt uden for sporskiftet (3), og som indbefatter mindst ét koblingsapparat, der via ledninger er forbundet med varmeanordningerne (14) i sporskiftet (3), såvel som måleanordninger til en tidsmæssig registrering af driftsstrøm, spænding og isoleringsmodstand og midler til begrænsning af den maksimale effekt, mindst ét kommunikationsmiddel, der er anbragt i tilslutningsdåsen og er forbundet med styreanordningen, og mindst én nedbørssensor til registrering af nedbørstypen og nedbørsmængden, der er forbundet med styreanordningen, hvilken fremgangsmåde omfatter følgende trin:

a) fastsættelse af mindst ét sporskiftesegment til den venstre side (5) af det i det mindste ene sporskifte (3) og/eller til den højre side (6) af det i det mindste ene sporskifte (3) med en specifik længde, hvor sporskiftesegmentet i det i det mindste ene sporskifte (3) omfatter en sideskinne (7), en tungeskinne (8), en glidestolsplade (9) og mindst én varmeanordning (14), og adskillelse af det i det mindste ene sporskiftesegment i enkelte afsnit med hver især mindst ét første knudepunkt, der svarer til mindst ét funktionsrelevant sted (19) i sporskiftesegmentet i det i det mindste ene sporskifte (3) om vinteren, hvor det funktionsrelevante sted (19) indeholder mindst ét målepunkt (37, 38, 39, 40, 41, 42, 43),

hvor det i det mindste ene sporskiftesegment repræsentativt afbilder det i det mindste ene sporskifte (3) termodynamisk,

hvor det i det mindste ene sporskiftesegment er placeret i nærheden af den i det mindste ene sporskiftetemperatursensor (28),

b) dannelse af et varmenet (26) til det i det mindste ene sporskiftesegment til den venstre side (5) af det i det mindste ene sporskifte (3) og/eller dannelse af et varmenet (27) til det i det mindste ene sporskiftesegment til den højre side (6) af det i det mindste ene sporskifte (3), hvor varmenettet (26, 27) indbefatter varmegenererende elementer, varmeoverførende elementer og varmeakkumulatorer (32), og tilordning af det respektive i det mindste ene knudepunkt (K) i de respektive afsnit af det i det mindste ene sporskiftesegment til mindst ét målepunkt (37, 38, 39, 40, 41, 42, 43),

hvor alle knudepunkter (K) i de enkelte afsnit via masker forbindes til et varmenet (26, 27) på en sådan måde, at forskellen mellem alle temperaturer med fortegn er lig med nul,

c) beregning af det tidsmæssige forløb af en optimal specifik effekt (P_{op}) af det i det mindste ene sporskiftesegment og den respektive optimale sporskiftetemperatur (T_{op}) ved det i det mindste ene første knudepunkt i sporskifteopvarmningen (1) ved det i det mindste ene sporskiftesegment via en effektopgørelse i henhold til et knudepunktssæt, og under driften aktivering af denne optimale specifikke effekt (P_{op}) ved den tilhørende varmeanordning (14) ved hjælp af produktet af faktisk specifik effekt (P) i varmeanordningen (14), der svarer til den maksimale specifikke effekt, og et effektforhold, hvor effektforholdet variabelt svarer til mellem 25 % og 100 % af den faktiske specifikke effekt (P),

d) registrering af det tidsmæssige forløb af den faktiske sporskiftetemperatur (T_W) ved det i det mindste ene sporskiftesegment med den i det mindste ene sporskiftetemperatursensor (28) og korrektion af den beregnede sporskiftetemperatur ved en af de i det mindste første knudepunkter i det i det mindste ene sporskiftesegment via effekt af konvektionsvarme (P_K), når den beregnede sporskiftetemperatur er højere end den faktiske sporskiftetemperatur (T_W), eller effekt af strålingsvarme (P_{St}) i varmenettet, når den beregnede sporskiftetemperatur er lavere end den faktiske sporskiftetemperatur,

e) beregning af sporskiftesluttemperaturen ved mindst ét yderligere knudepunkt i det i det mindste ene sporskiftesegment og sammenligning af den beregnede sporskiftesluttemperatur med en parametriseret minimumssporskiftetemperatur (T_{min}) for dette i det mindste ene yderligere knudepunkt, hvor en nominel sporskiftetemperatur (T_{Soll}), der kan parametriseres, hvis minimumssporskiftetemperaturen (T_{min}) for sporskiftet (3) ikke nås, øges med en korrektionsfaktor (y) for den nominelle sporskiftetemperatur, indtil den respektive beregnede sporskiftesluttemperatur for sporskiftet (3) mindst svarer til minimumssporskiftetemperaturen (T_{min}) for sporskiftet (3),

f) beregning af opvarmningstiden (t_A) for opvarmningen af det i det mindste ene sporskiftesegment indtil den nominelle sporskiftetemperatur (T_{Soll}), der kan parametriseres, for sporskiftet (3) og vurdering af den beregnede opvarmningstid (t_A) ved nominel sporskiftetemperatur (T_{Soll}), der kan parametriseres,

hvor den optimale specifikke effekt (P_{op}) øges i forbindelse med et underskud, og den optimale specifikke effekt (P_{op}) reduceres i forbindelse med et overskud,

g) beregning af opvarmningstiden (t_A) for opvarmningen af det i det mindste ene sporskiftesegment indtil minimumssporskiftetemperaturen (T_{min}), der kan parametriseres, for sporskiftet (3) og vurdering af den nødvendige specifikke effekt (P_{erf}) ud fra bevaringseffekt (P_{erh}) og smelteeffekt (P_{sm}) for sneen, der er faldet indtil da (h_S), med den specifikke effekt (P) ved minimumssporskiftetemperatur (T_{min}), der kan parametriseres,

hvor den optimale specifikke effekt (P_{op}) i forbindelse med et underskud øges, eller der genereres en melding „faldet snemængde er for stor og smeltes ikke“.

2. Fremgangsmåde ifølge krav 1, der desuden inden driften ved hjælp af et varmekrav omfatter trinnet

h) beregning af den specifikke smelteeffekt (P) for snemængden, der under opvarmningstiden (t_A) er beregnet ved sporskiftesegmentet, ud fra en meddelt snehøjde pr. tidsenhed og beregning af den specifikke bevaringseffekt (P_{erh}) til opretholdelse af smeltetemperaturen (P_{sm}) ved sporskiftesegmentet og sammenligning af summen af denne med varmeanordningens (14) faktiske specifikke effekt (P) og, hvis den faktiske specifikke effekt (P) af varmeanordningen (14) er lavere, aktivering af sporskifteopvarmningen (1) med en anden nominel sporskiftetemperatur ($T_{Soll\text{-}Vor}$), der er så høj, at varmeanordningens (14) specifikke effekt (P) under driften i det mindste er lig med summen af specifik smelteeffekt (P_{sm}) og bevaringseffekt (P_{erh}).

3. Fremgangsmåde ifølge krav 1 eller 2, hvor

De varmegenererende elementer omfatter den specifikke effekt (P) af den i det mindste ene varmeanordning (14) med en varmeakkumulator i sporskiftesegmentet og en varmeoverførsel ved hjælp af varmestråling, og/eller

de varmeoverførende elementer omfatter varmemodstande ved sporskiftet (3) fra materialeegenskaberne, de geometriske størrelser og de fremherskende belastninger som følge af varmeoverførsel og omgivelser ved det i det mindste ene sporskiftesegment.

4. Fremgangsmåde ifølge et af kravene 1 til 3, hvor i trin f)

opvarmningstiden (t_A) for opvarmningen af det i det mindste ene sporskiftesegment beregnes på baggrund af summen af enkelte opvarmningstider for det i det mindste ene sporskiftesegment til opvarmning af dette, for smeltning af sne og for fordampning af vand i denne, og/eller

opvarmningstiden (t_A) forlænges ved forøgelse af effektforholdet og/eller omskiftning fra normal drift til permanent drift og/eller reduceres ved reduktion af effektforholdet.

5. Fremgangsmåde ifølge et af kravene 1 til 4, der ved aktiv opvarmning desuden omfatter trinnene

i) beregning af en smelteeffekt (P_{sm}) for falden sne (h_S) i et tidsrum, der kan parametriseres, og sammenligning af denne smelteeffekt med forskellen mellem specifik effekt (P) og en beregnet bevaringseffekt (P_{erh}), hvor effekten (P_{erf}) i forbindelse med et underskud af den specifikke effekt forøges og/eller en permanent opvarmning indledes og/eller en første advarselsmelding udsendes,

og/eller

j) sammenligning af den beregnede opvarmningstid (t_A) med en maksimal opvarmningstide, der kan parametriseres, hvor effekten i forbindelse med et underskud af den specifikke effekt forøges og/eller en permanent opvarmning indledes og/eller en anden advarselsmelding udsendes,

og/eller

k) beregning af snehøjden (h_S) på baggrund af forskellen mellem faldet snehøjde og smeltet snehøjde pr. tidsenhed og sammenligning af den beregnede snehøjde med en maksimalt tilladt snehøjde, der kan parametriseres, hvor effekten i forbindelse med et underskud af den specifikke effekt forøges og/eller en permanent opvarmning indledes og/eller en tredje advarselsmelding udsendes.

6. Fremgangsmåde ifølge et af kravene 1 til 5, hvor beregningen af opvarmningstiden (t_A) i trin f) omfatter undertrinnene:

f1) beregning af dødtiden (t_T) for det i det mindste ene sporskiftesegment på baggrund af det tidsmæssige forløb af sporskiftetemperaturen (T_W) i sporskiftet (3) ved optimal (P_{op}) eller faktisk specifik effekt (P),

f2) beregning af tiden t_{A1} til opvarmning af det i det mindste ene sporskiftesegment fra sporskiftetemperaturen af den kolde skinne i sporskiftet (3) og smeltetemperaturen (T_s) til minimumssporskiftetemperaturen (T_{min}) ved mindst ét knudepunkt,

f3) beregning af tiden t_{A2} til smeltning af snemængden under trin f2) på baggrund af forskellen mellem forelliggende specifik effekt fratrukket effekten (P_{erh}) til opretholdelse af minimumssporskiftetemperaturen (T_{min}) i det i det mindste ene sporskiftesegment,

f4) beregning af tiden t_{A3} til smeltning af den faldne sne under trin f3) på baggrund af forskellen mellem forelliggende specifik effekt fratrukket effekten (P_{erh}) til opretholdelse af minimumssporskiftetemperaturen (T_{min}) i det i det mindste ene sporskiftesegment,

f5) beregning af tiden t_{A4} til opvarmning af det i det mindste ene sporskiftesegment på baggrund af forskellen mellem minimumssporskiftetemperatur og den nominelle sporskiftetemperatur (T_{soll}) ved knudepunktet med sporskiftetemperatursensoren (28) til sporskiftet (3),

f6) beregning af tiden t_{A5} til smeltning af den faldne sne under trin f5) på baggrund af forskellen mellem forelliggende specifik effekt (P) fratrukket effekten (P_{erh}) til opretholdelse af minimumssporskiftetemperaturen (T_{min}) i det i det mindste ene sporskiftesegment.

7. Fremgangsmåde ifølge et af kravene 1 til 6, der desuden omfatter en beregning af driftsgrænsen omgivelsestemperatur ($G_{W\text{-}Tu}$) for sporskifteopvarmningen (1), omfattende

- beregning af de optionelle sporskifteseluttemperaturer (T_{op}) ved to specifikke knudepunkter i det i det mindste ene sporskiftesegment, hvilke svarer til hovedsideskinnen (20) og hovedtungeskinnen (21) som funktionsrelevante steder (19) i det i det mindste ene sporskifte (3), hvor de beregnede sporskiftetemperaturer for hovedsideskinnen (20) og hovedtungeskinnen (21) trækkes fra minimumssporskiftetemperaturen (T_{min}) og den laveste af disse svarer til driftsgrænse-omgivelsestemperaturen.

8. Fremgangsmåde ifølge et af kravene 1 til 7, der desuden omfatter en beregning af driftsgrænsen snemængde ($G_{W\text{-}hs}$) for sporskifteopvarmningen (1), omfattende

- beregning af en specifik bevaringseffekt (P_{erh}) ved minimumssporskiftetemperaturen (T_{min}) for sporskiftet (3), plus en tolerance for minimumssporskiftetemperatur $\Delta t_{,min}$, ved sideskinnefoden, en smelteeffekt (P_{sm}) for den maksimale snemængde eller snemængden (h_s), der er registreret indtil da, samt en fordampningseffekt (P_V) for smeltevand og sammenligning af summen heraf med varmeanordningens (14) nødvendige specifikke effekt (P_{erf}) til det i det mindste ene sporskiftesegment, når varmeanordningens nødvendige specifikke effekt (P) er mindre end summen af bevaringseffekt (P_{erh}) og smelteeffekt (P_{sm}) og fordampningseffekt driftsgrænsen snehøjde er overskredet.

9. Fremgangsmåde ifølge et af kravene 1 til 8, der desuden omfatter en projektspecifik dimensionering af varmeanordningerne (14) og deres nødvendige specifikke effekt (P_{erf}), omfattende

- beregning af en specifik effekt (P) af varmeanordningen til opnåelse af en nominel sporskiftetemperatur (T_{soll}) for sporskiftet (3) ved sporskiftetemperatursensorens (28) placering og en minimal sporskiftetemperatur T_{w-min} for sporskiftet (3) ved mindst én hovedsideskinne (20) og/eller én hovedtungeskinne (21) for det i det mindste ene sporskiftesegment via beregning af summen af varmeledning, stråling og konvektion til omgivelserne, varmekapacitet og latent varme ved sne og vanding, når der foreligger driftsgrænseværdier fra minimal omgivelsestemperatur (T_U), skinneprofil, maksimal vindhastighed (v_{max}) og maksimal snehøjde pr. time, og

- forøgelse af den nødvendige specifikke effekt (P_{erf}), når den beregnede faktiske specifikke effekt (P) er mindre end den specifikke effekt, der svarer til den nødvendige smelteeffekt (P_{sm}) i opvarmningstiden (t_A), der beregnes fra minimal omgivelsestemperatur til opnåelse af en skinnetemperatur på mindst 0 °C, for snemængden, der opstår af produktet af opvarmningstid (t_A) og snehøjde (h_s) pr. time, og fordampningseffekten (P_v) af resterende smeltevand og den nødvendige specifikke bevaringseffekt (P_{erf}) for en skinnetemperatur på 0 °C ved de funktionsrelevante steder (19) i det i det mindste ene sporskiftesegment.

10. Fremgangsmåde ifølge et af kravene 1 til 9, hvor

- der under drift af sporskifteanordningen (1) foretages en indstilling af den optimale specifikke effekt for varmeanordningerne (14), der svarer til produktet af specifik effekt og et effektforhold på 25 % til 100 %, via de respektive koblingsapparater til tilkobling og frakobling af varmeanordningerne (14) ved hjælp af ændring af indkoblingstiden eller frekvensen eller impulsbredden eller bølgegruppestyring eller gruppedrift,

og/eller

- effektforholdet udgør mellem 25 % og 100 %, hvor den specifikke effekt (P) af den venstre side (5) af sporskiftet (3) og den højre side (6) af sporskiftet (3) under drift af sporskifteopvarmningen (1) maksimalt svarer til middelværdien og/eller meridianen af varmeanordningens (14) specifikke effekt,

og/eller

- den beregnede specifikke effekt (P_{op}) til den venstre side (5) af sporskiftet (3) og den højre side (6) af sporskiftet (3) under drift af sporskifteopvarmningen (1) maksimalt svarer til varmeanordningernes (14) specifikke effekt (P),

eller en specifik effektforskel for den venstre side (5) af sporskiftet (3) eller den højre side (6) af sporskiftet (3) beregnes på baggrund af forskellen mellem varmeanordningernes (14) specifikke effekt (P) fratrukket beregnet specifik effekt (P_{op}), og denne specifikke effektforskel i forbindelse med en positiv effektforskel ved den venstre side (5) af sporskiftet (3) eller den højre side (6) af sporskiftet (3) stilles til rådighed for den respektive anden side af sporskiftet (3) foruden varmeanordningens (14) specifikke effekt (P), således at der opstår et ensartet tidsmæssigt forløb af skinnetemperaturerne i sporskiftet (3) på den venstre side (5) af sporskiftet (3) og på den højre side (6) af sporskiftet (3) ved de funktionsrelevante steder (19) i sporskiftet (3).

11. Styreanordning til styring og regulering af en sporskiftetemperatur i en sporskifteopvarmning (1), der er indrettet til at gennemføre fremgangsmåden ifølge et af kravene 1 til 10, hvor sporskifteopvarmningen (1) indeholder mindst én varmeanordning (14), der er anbragt på mindst ét sporskifte (3), mindst én sporskiftetemperatursensor (28) på det i det mindste ene sporskifte (3) og mindst én energifordeling med mindst ét varmeudtag pr. sporskifte (3), hvilken styreanordning omfatter:

- en CPU til beregning af sporskiftetemperaturerne i sporskiftet (3) for mindst ét sporskiftesegment, der via kommunikationsmidler er forbundet med styreanordningen,

- mindst én tilslutningsdåse, som er anbragt uden for sporskiftet (3), og som indbefatter mindst ét koblingsapparat, der via ledninger er forbundet med varmeanordningerne (14) i sporskiftet (3), såvel som måleanordninger til en tidsmæssig registrering af driftsstrøm, spænding og isoleringsmodstand og midler til begrænsning af den maksimale effekt,

- mindst ét kommunikationsmiddel, der er anbragt i tilslutningsdåsen og er forbundet med styreanordningen,

- mindst én nedbørssensor til registrering af nedbørstypen og nedbørsmængden, der er forbundet med styreanordningen.

Fig. 0

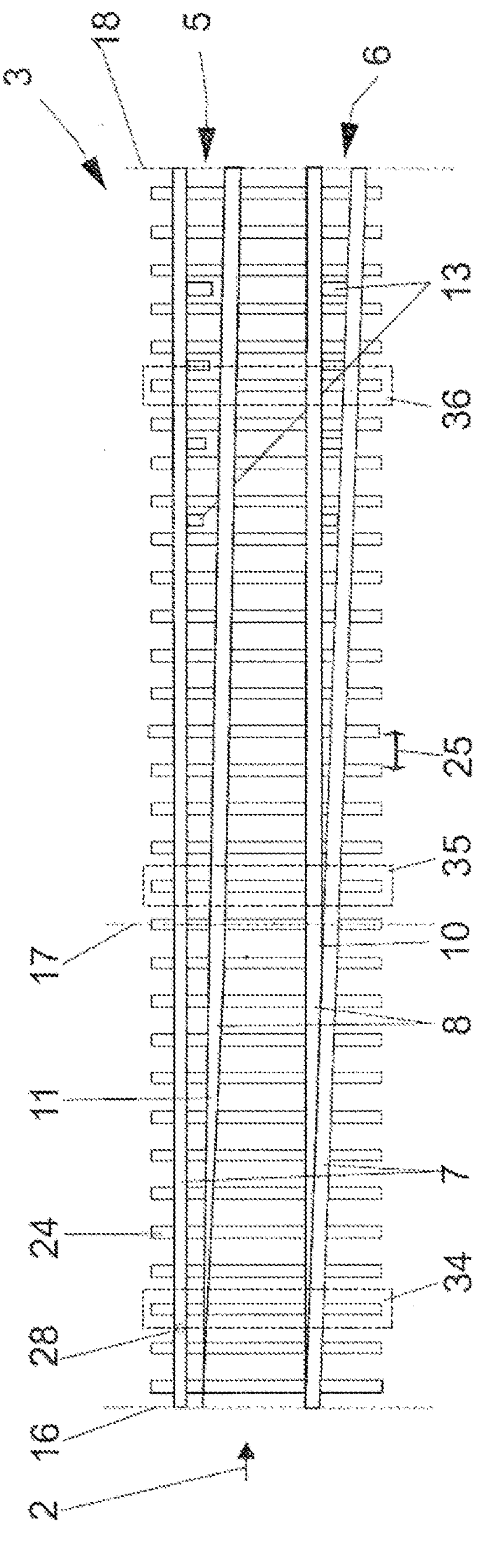


Fig. 1

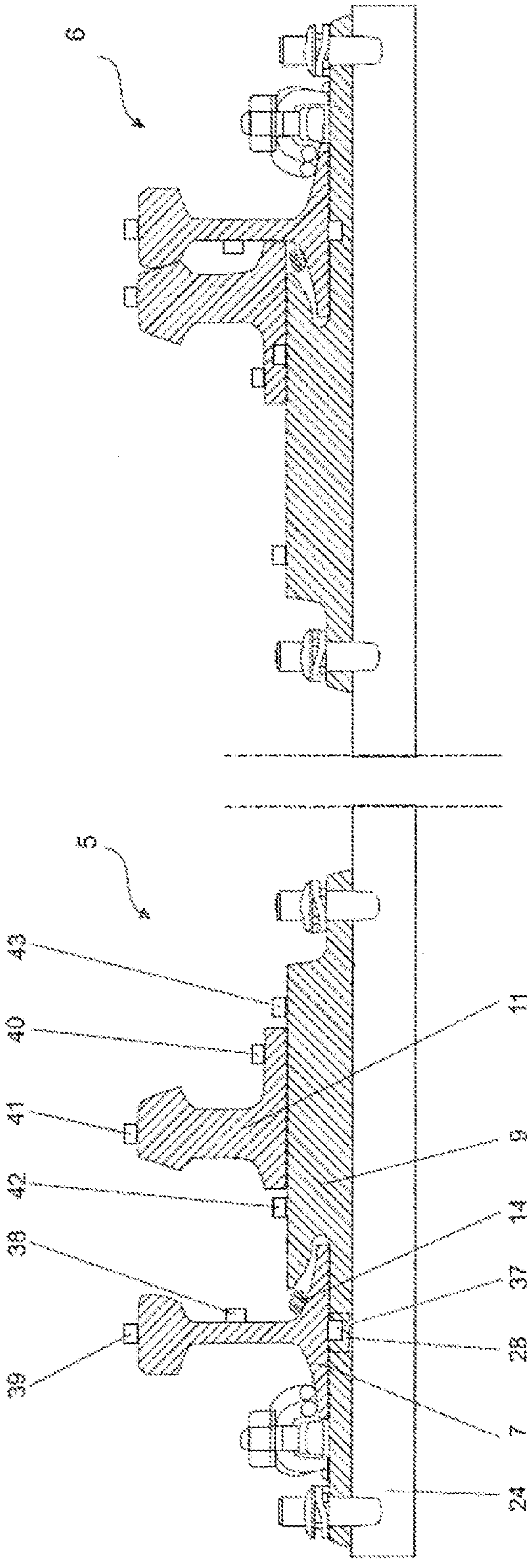


Fig. 2

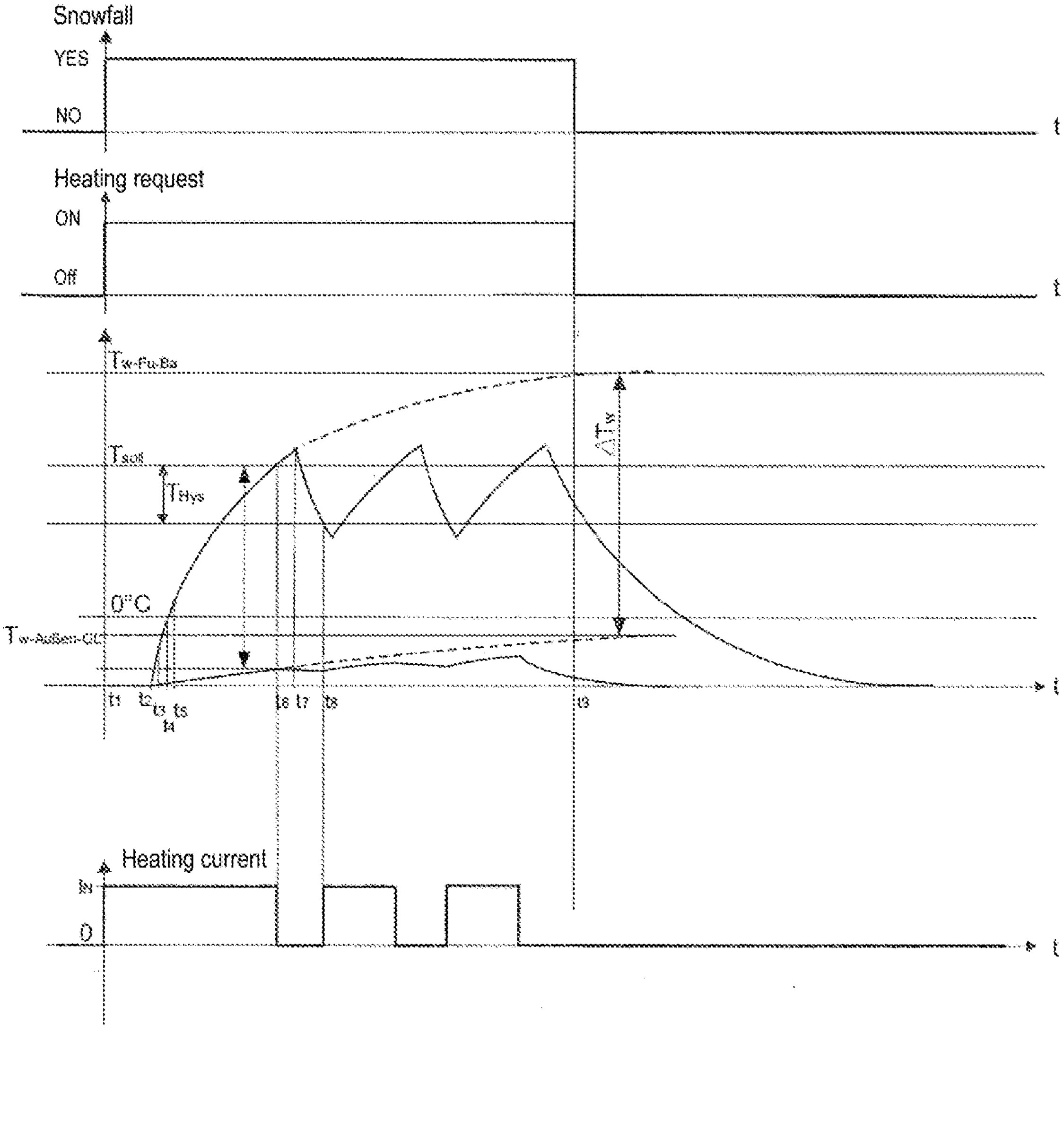

Snowfall
YES
NO
t
Heating request
ON
Off
t
Tw-Fu-Ba
Tsoll
THys
ΔTw
0°C
Tw-Außen-GC
t1
t2
t3
t4
t5
t6
t7
t8
t9
t
Heating current
IN
0
t

Fig. 3

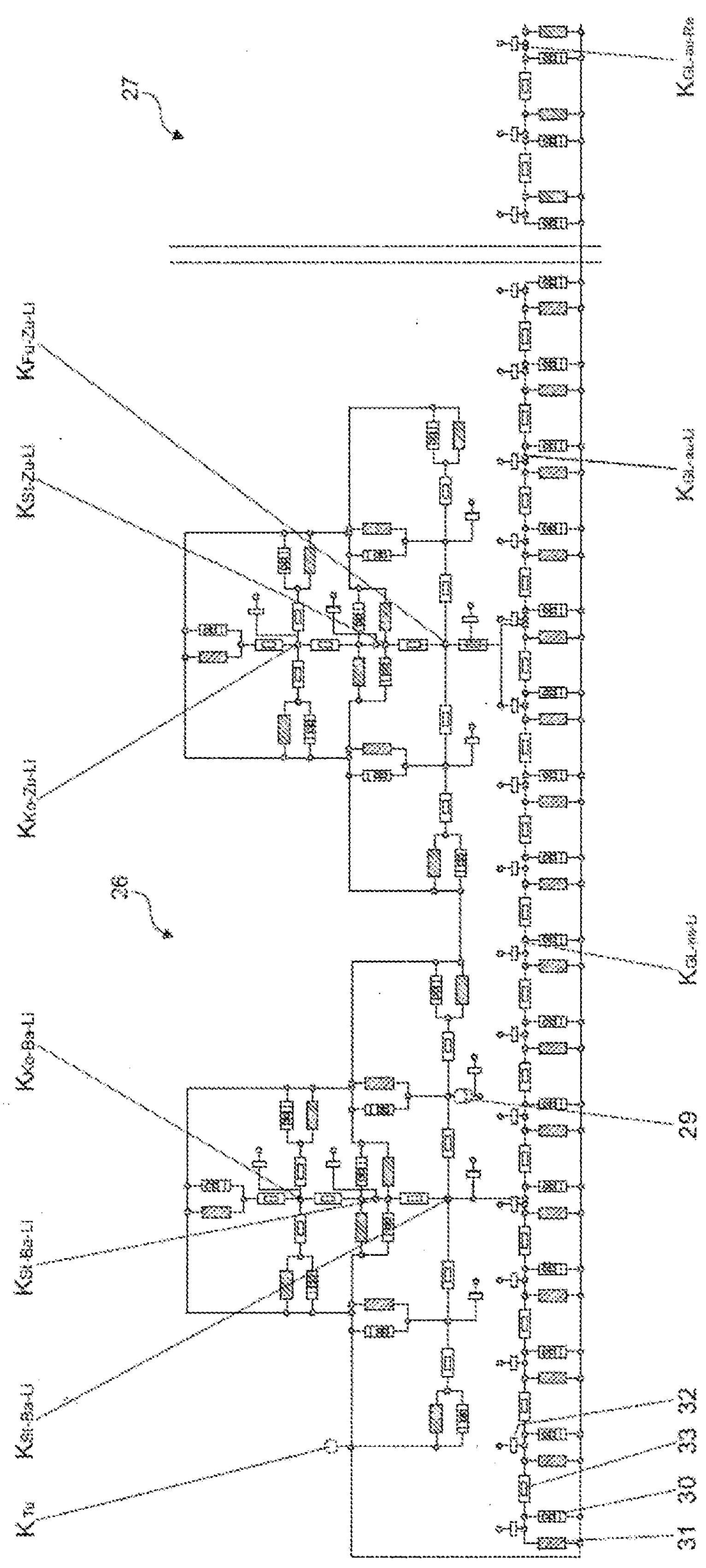


Fig. 4

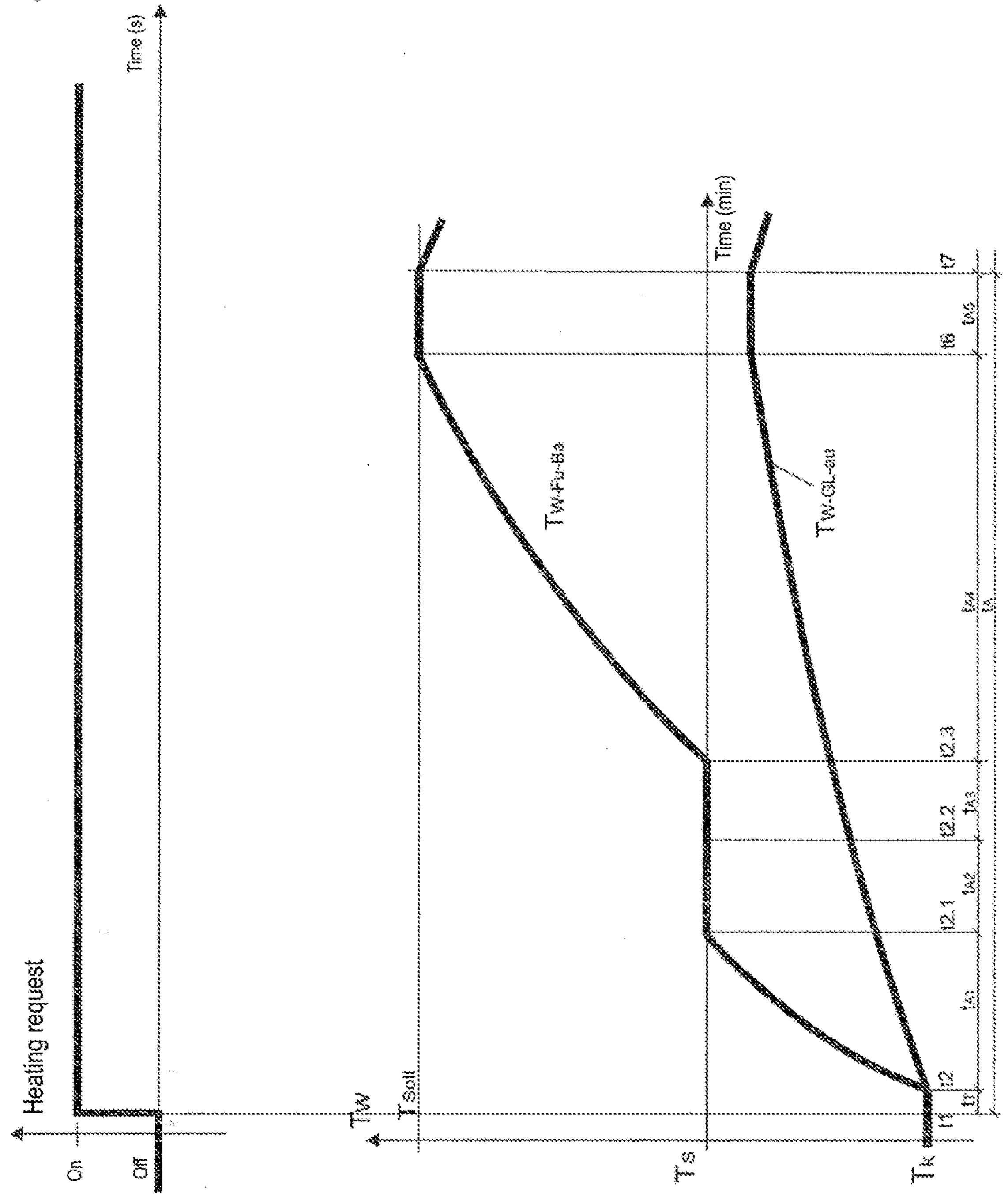

Heating request
On
Off
Time (s)
TW
T Soll
T S
T k
Time (min)
TW-Fu-Ba
TW-GL-au
t1
t2
t2.1
t2.2
t2.3
t6
t7
tA1
tA2
tA3
tA4
tA5
tA

Fig. 5

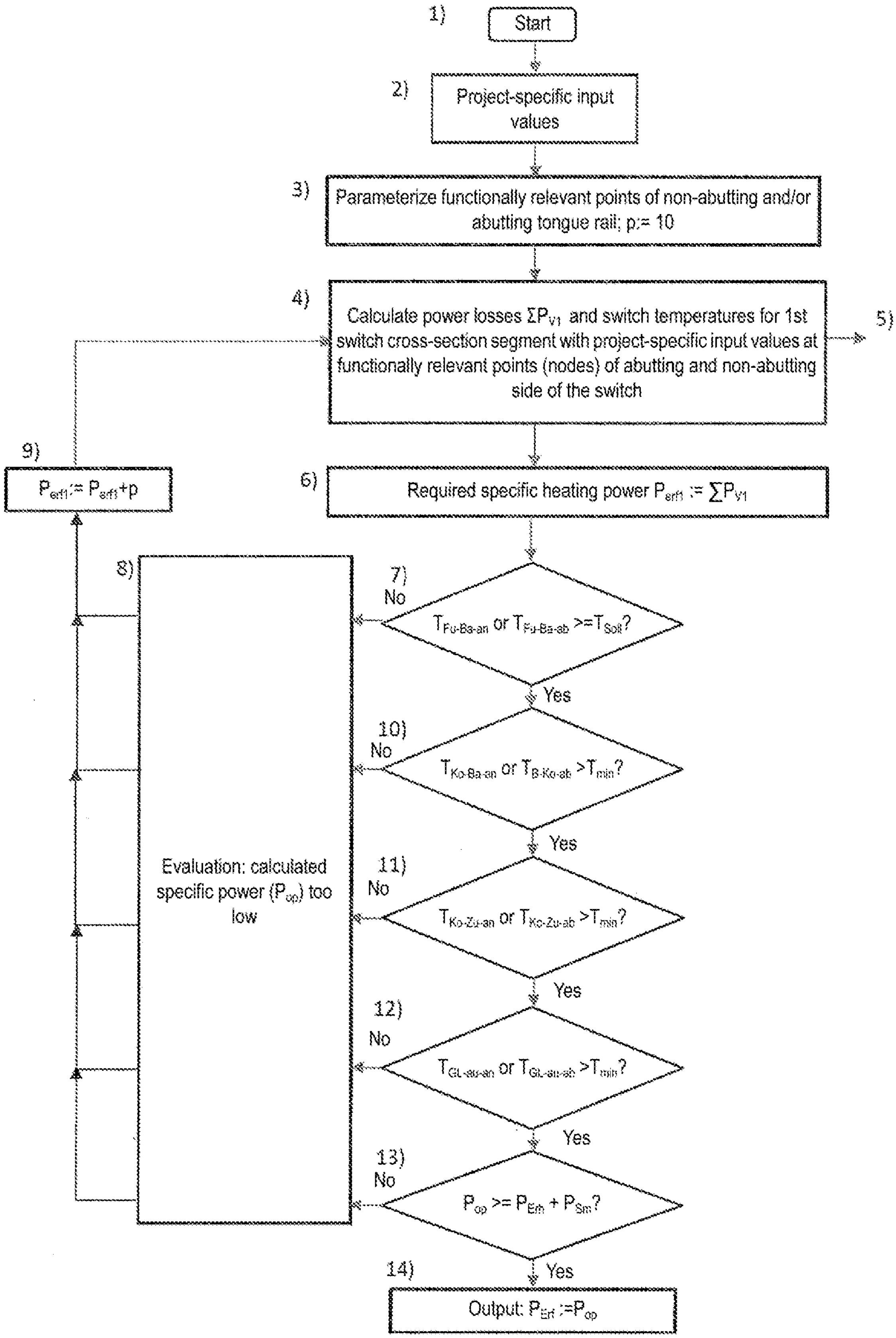

1)
Start
2)
Project-specific input values
3)
Parameterize functionally relevant points of non-abutting and/or abutting tongue rail; p:= 10
4)
Calculate power losses ΣP_V1 and switch temperatures for 1st switch cross-section segment with project-specific input values at functionally relevant points (nodes) of abutting and non-abutting side of the switch
5)
9)
P_erf1 := P_erf1+p
6)
Required specific heating power P_erf1 := ΣP_V1
8)
Evaluation: calculated specific power (P_op) too low
7)
No
T_Fu-Ba-an or T_Fu-Ba-ab >=T_Soll?
Yes
10)
No
T_Ko-Ba-an or T_B-Ko-ab >T_min?
Yes
11)
No
T_Ko-Zu-an or T_Ko-Zu-ab >T_min?
Yes
12)
No
T_GL-au-an or T_GL-au-ab >T_min?
Yes
13)
No
P_op >= P_Erh + P_Sm?
Yes
14)
Output: P_Erf :=P_op

Fig. 6

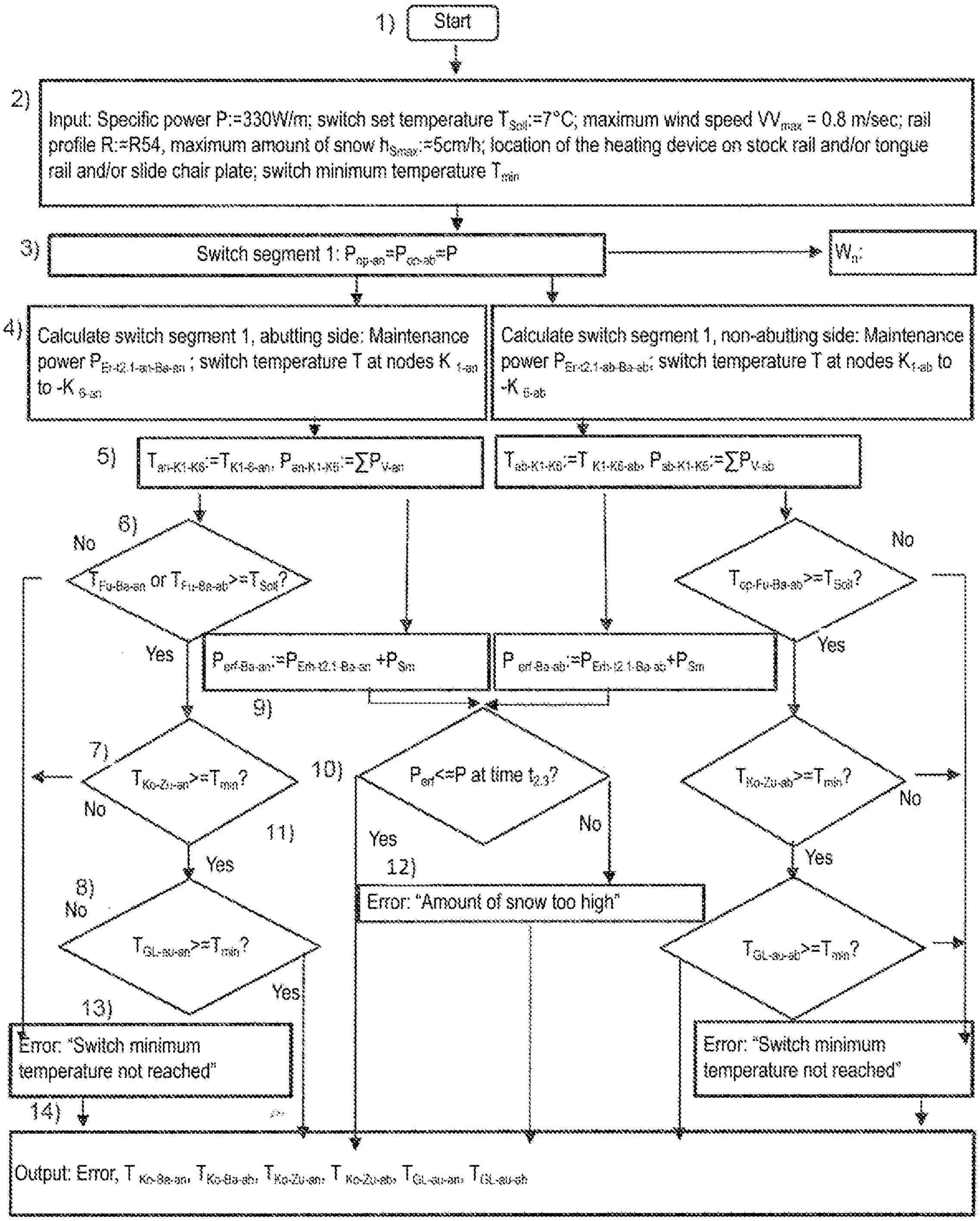

1) Start
2) Input: Specific power P:=330W/m; switch set temperature T_Soll:=7°C; maximum wind speed VV_max = 0.8 m/sec; rail profile R:=R54, maximum amount of snow h_Smax:=5cm/h; location of the heating device on stock rail and/or tongue rail and/or slide chair plate; switch minimum temperature T_min
3) Switch segment 1: P_op-an=P_op-ab=P
W_n:
4) Calculate switch segment 1, abutting side: Maintenance power P_Er-t2.1-an-Ba-an ; switch temperature T at nodes K 1-an to -K 6-an
Calculate switch segment 1, non-abutting side: Maintenance power P_Er-t2.1-ab-Ba-ab; switch temperature T at nodes K1-ab to -K 6-ab
5) T_an-K1-K6:=T_K1-6-an, P_an-K1-K6:=∑P_V-an
T_ab-K1-K6:=T K1-K6-ab, P_ab-K1-K6:=∑P_V-ab
6) T_Fu-Ba-an or T_Fu-Ba-ab>=T_Soll?
T_op-Fu-Ba-ab>=T_Soll?
No
Yes
P_erf-Ba-an:=P_Erh-t2.1-Ba-an +P_Sm
P erf-Ba-ab:=P_Erh-t2.1-Ba-ab+P_Sm
9)
7) T_Ko-Zu-an>=T_min?
10) P_erf<=P at time t_2.3?
T_Ko-Zu-ab>=T_min?
11)
12) Error: "Amount of snow too high"
8) T_GL-au-an>=T_min?
T_GL-au-ab>=T_min?
13) Error: "Switch minimum temperature not reached"
Error: "Switch minimum temperature not reached"
14) Output: Error, T Ko-Ba-an, T_Ko-Ba-ab, T_Ko-Zu-an, T Ko-Zu-ab, T_GL-au-an, T_GL-au-ab

Fig. 7a

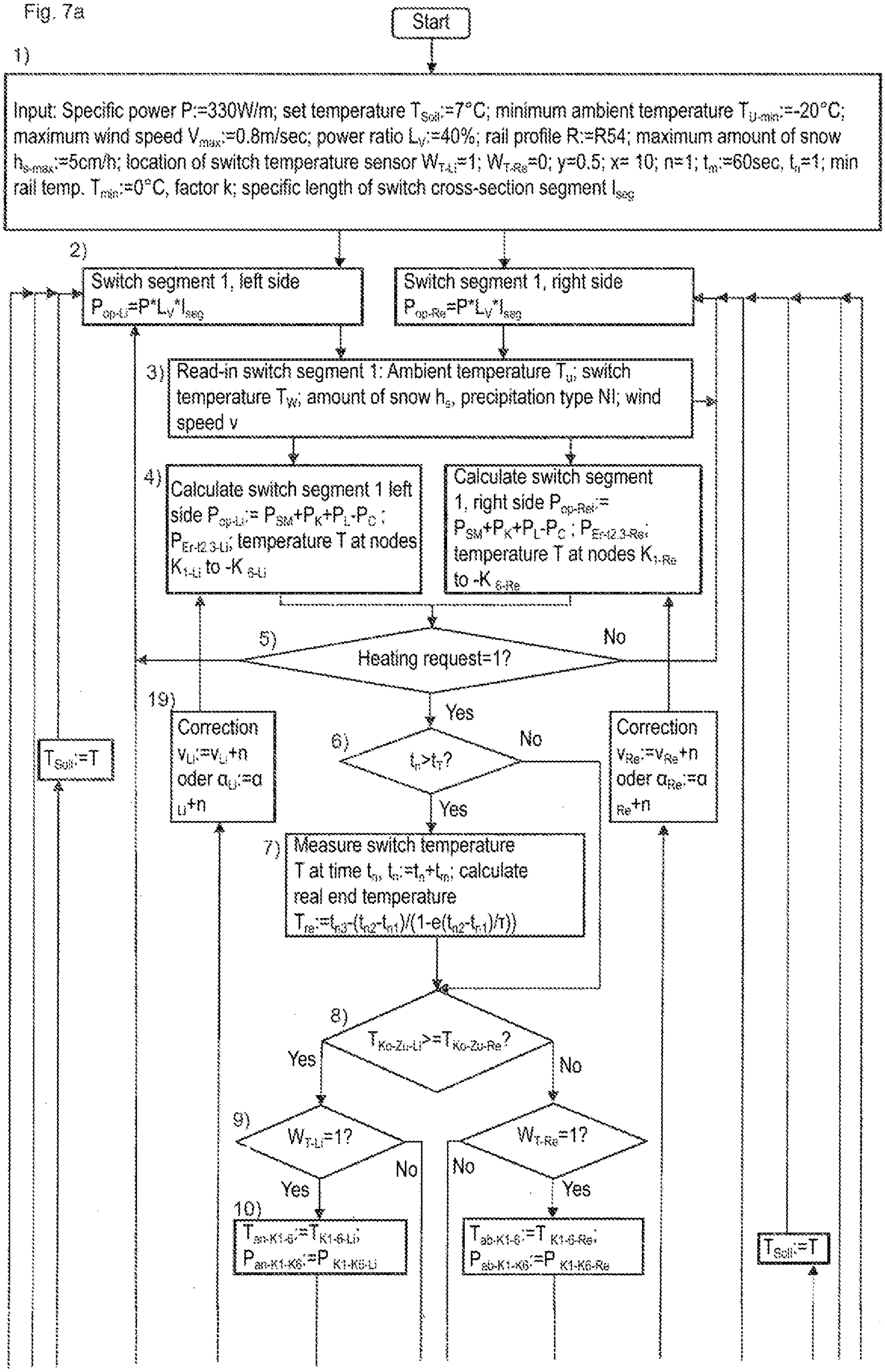
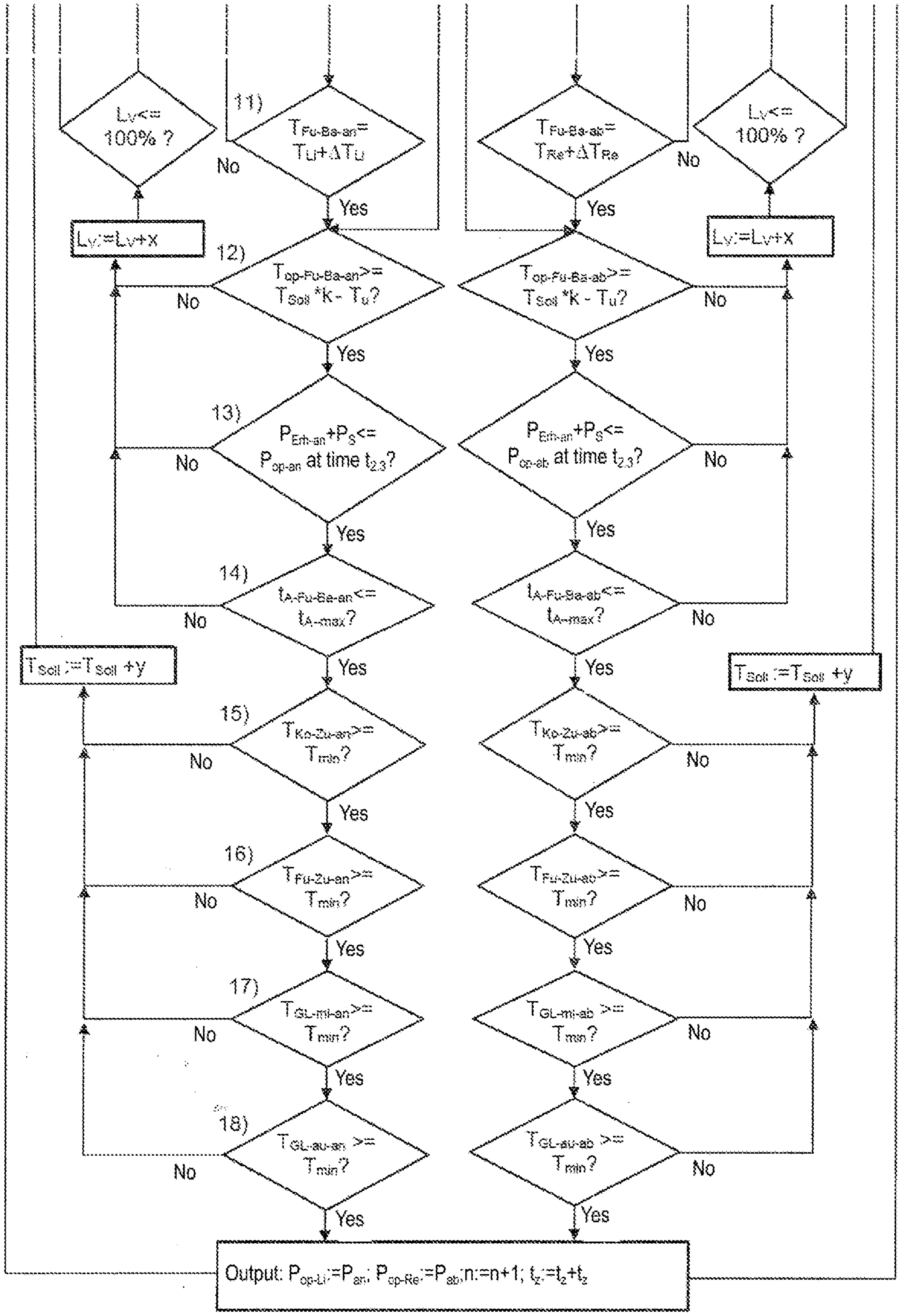

Start
1)
Input: Specific power P:=330W/m; set temperature T_Soll:=7°C; minimum ambient temperature T_U-min:=-20°C; maximum wind speed V_max:=0.8m/sec; power ratio L_V:=40%; rail profile R:=R54; maximum amount of snow h_s-max:=5cm/h; location of switch temperature sensor W_T-Li=1; W_T-Re=0; y=0.5; x= 10; n=1; t_m:=60sec, t_n=1; min rail temp. T_min:=0°C, factor k; specific length of switch cross-section segment l_seg
2)
Switch segment 1, left side P_op-Li=P*L_V*l_seg
Switch segment 1, right side P_op-Re=P*L_V*l_seg
3) Read-in switch segment 1: Ambient temperature T_u; switch temperature T_W; amount of snow h_s, precipitation type NI; wind speed v
4) Calculate switch segment 1 left side P_op-Li:= P_SM+P_K+P_L-P_C ; P_Er-t2.3-Li; temperature T at nodes K_1-Li to -K_6-Li
Calculate switch segment 1, right side P_op-Re:= P_SM+P_K+P_L-P_C ; P_Er-t2.3-Re; temperature T at nodes K_1-Re to -K_6-Re
5) Heating request=1?
No
Yes
19) Correction v_Li:=v_Li+n oder α_Li:=α_Li+n
Correction v_Re:=v_Re+n oder α_Re:=α_Re+n
T_Soll:=T
6) t_n>t_T?
No
Yes
7) Measure switch temperature T at time t_n, t_n:=t_n+t_m; calculate real end temperature T_re:=t_n3-(t_n2-t_n1)/(1-e(t_n2-t_n1)/τ))
8) T_Ko-Zu-Li>=T_Ko-Zu-Re?
Yes
No
9) W_T-Li=1?
W_T-Re=1?
No
No
Yes
Yes
10) T_an-K1-6:=T_K1-6-Li; P_an-K1-K6:=P_K1-K6-Li
T_ab-K1-6:=T_K1-6-Re; P_ab-K1-K6:=P_K1-K6-Re
T_Soll:=T

Fig. 7b



11)
12)
13)
14)
15)
16)
17)
18)
Lv<= 100% ?
Lv:=Lv+x
TFu-Ba-an= Tu+ΔTu
TFu-Ba-ab= TRe+ΔTRe
Top-Fu-Ba-an>= TSoll *K - Tu?
Top-Fu-Ba-ab>= TSoll *K - Tu?
PErh-an+PS<= Pop-an at time t2,3?
PErh-an+PS<= Pop-ab at time t2,3?
tA-Fu-Ba-an<= tA-max?
tA-Fu-Ba-ab<= tA-max?
TSoll :=TSoll +y
TKo-Zu-an>= Tmin?
TKo-Zu-ab>= Tmin?
TFu-Zu-an>= Tmin?
TFu-Zu-ab>= Tmin?
TGL-mi-an>= Tmin?
TGL-mi-ab >= Tmin?
TGL-au-an >= Tmin?
TGL-au-ab >= Tmin?
Yes
No
Output: Pop-Li:=Pan; Pop-Re:=Pab;n:=n+1; tz:=tz+tz