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(54) **Method and system for controlling a plurality of refrigerating machines**

(57) A control system (11) for controlling a plurality of refrigerating machines (2) of an air-conditioning plant (1) having fan coil units (3) connected to the refrigerating machines (2) via an hydronic circuit (4) within which a coolant flows, the hydronic circuit (4) having a bypass duct (9) connecting a delivery duct (5) with a return duct (6), the control system (11) having: temperature sensors (12-14) to measure the temperature (TDLV) of the fluid in the delivery duct (5) upstream of the bypass duct (9), the temperature (TRET) of the fluid in the return duct (6) and the temperature (TLIN) of the fluid in the delivery duct (5) downstream of the bypass duct (9); a supervision unit (15) configured to provide an estimate of the thermal load (PLE) of the service circuit (4) as a function of the measured temperatures (TDLV, TRET, TLIN) and to determine operating states (ST_i) and part load ratios (PLR_i) to set for the refrigerating machines (2) such as to enable them to provide an overall cooling capacity that satisfies the estimated thermal load (PLE) with the minimum consumption of electric power.

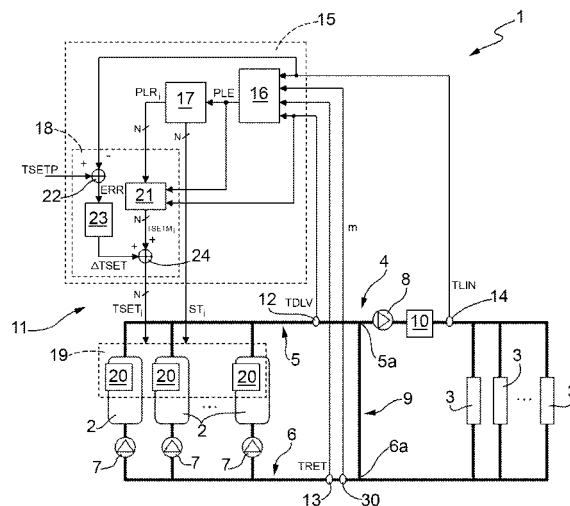


FIG.1

Description

[0001] The present invention relates to a method and a system for controlling a plurality of refrigerating machines of an air-conditioning plant.

[0002] In particular, the present invention is advantageously, but not exclusively intended for use to control domestic HVAC (Heating, Ventilation and Air-Conditioning) plants that comprise a plurality of refrigerating machines consisting of fluid coolers and/or hydronic heat pumps connected in parallel, to which the following description specifically refers but without any loss of generality.

[0003] Air-conditioning plants are known in the prior art that comprise a plurality of refrigerating machines connected in parallel and one or more convection units, for example fan coil units or ordinary water radiators, appropriately arranged within a building in which the air-conditioning is to be controlled and hydraulically connected to the refrigerating machines via a hydronic circuit, within which a service fluid flows, said fluid consisting of a water-based coolant, and said circuit having a delivery duct within which the service fluid flows from the refrigerating machines to the convection units and a return duct within which the service fluid flows in the opposite direction.

[0004] Said air-conditioning plant comprises a plurality of pumps, each of which is connected to a respective refrigerating machine to force the flow of the service fluid through said machine when it is on, and at least an additional pump arranged on the delivery duct to distribute a constant flow of the service fluid to the convection units. The hydronic circuit typically comprises a bypass duct connecting the delivery duct, upstream of the distribution pump, directly to the return duct so as to disconnect, in terms of the flow of service fluid, the part of the plant with the refrigerating machines from that with the convection units. Normally, each refrigerating machine is capable of part load operation, i.e. it can deliver cooling capacity according to a plurality of capacity steps.

[0005] The air-conditioning plant comprises a control system to control the operation of the refrigerating machines. Control systems are known in the prior art that comprise a temperature sensor to measure the delivery temperature or return temperature of the service fluid and a control unit to control switching on and/or part load operation of the refrigerating machines so that the measured temperature follows a preset setpoint that is the same throughout the plant.

[0006] Two methods are known in the prior art for controlling the refrigerating machines. In a first method an additional refrigerating machine is only switched on if those that are already on are already running at their maximum cooling capacity. This method is also known as the "machine saturation strategy". In the second method all the refrigerating machines are brought to the same capacity step before bringing another refrigerating machine to the next capacity step. This method is also known as the "step saturation strategy".

[0007] However, neither of the above strategies achieve optimal energy efficiency as they do not exploit the peak efficiency of each refrigerating machine. Each refrigerating machine has a level of efficiency, expressed as the ratio between the cooling capacity delivered and the electric power consumed, which varies with the percentage of part load operation and which has a maximum value for a percentage of part load operation that is typically less than 100% and depends on the number of active compressors in the refrigerating machine, the architecture of the hydronic circuit and the machine's control logic. Moreover, the refrigerating machines may differ from one another and thus have a maximum efficiency value for different percentages of part load operation.

[0008] The object of the present invention is to provide a method for controlling a plurality of refrigerating machines of an air-conditioning plant and to provide a relative control system, which overcome the inconveniences described above and are, at the same time, easy and economic to produce.

[0009] According to the present invention there are provided a method and a control system for controlling a plurality of refrigerating machines for an air-conditioning plant as disclosed in the appended claims.

[0010] According to the present invention there is also provided an air-conditioning plant as disclosed in the appended claims.

[0011] In order to better understand the present invention, a non-limiting embodiment thereof will now be described by way of example with reference to the accompanying figures, in which:

- figure 1 is a schematic illustration of an air-conditioning plant provided with a control system implementing the method for controlling an air-conditioning plant according to the present invention; and
- figure 2 illustrates an example of a function linking two parameters used by the method for controlling an air-conditioning plant according to the invention.

[0012] With reference to figure 1, number 1 generally indicates an air-conditioning plant, as a whole, which comprises a plurality of refrigerating machines 2 connected in parallel and one or more convection units 3 consisting, for example, of fan coil units and connected to the refrigerating machines 2 via a hydronic circuit 4, within which a service fluid consisting of a water-based coolant flows. The hydronic circuit 4 comprises a main delivery duct 5 within which the service fluid flows from the refrigerating machines 2 to the convection units 3 and a main return duct 6 within which the service fluid flows in the opposite direction.

[0013] The plant 1 comprises a plurality of pumps 7, each of which is connected to a respective refrigerating machine 2 to force the flow of the service fluid through said machine 2 when the latter is on, at least one additional pump 8 arranged on the delivery duct 5 to distribute a constant flow of the service fluid to the convection units 3. The hydronic circuit 4 also comprises a bypass duct 9 connecting a point 5a on the delivery duct 5 upstream of the pump 8 and a point 6a on the return duct 6 to disconnect, in terms of the service fluid flow, the part of the plant with the refrigerating machines 2 from that with the convection units 3.

[0014] The plant 1 comprises a storage tank 10 arranged on the delivery duct 5 downstream of the bypass duct 9 to generate a thermal inertia in the hydronic circuit 4, slowing the dynamics of the plant 1 so as to prevent any undesirable oscillations in the control valves (not illustrated) of the convection units 3. The presence of the storage tank is, however, optional.

[0015] Each of the refrigerating machines 2 is capable of part load operation, i.e. it is able to deliver cooling capacity according to a plurality of capacity steps. For example, each refrigerating machine 2 comprises several compressors of a known type which can be switched on in an increasing number.

[0016] The plant 1 comprises a control system 11 for controlling the operation of the refrigerating machines 2. The control system 11 implements the method for controlling an air-conditioning plant of the invention, as described below.

[0017] The control system 11 comprises temperature sensing means, which are arranged along the hydronic circuit 4 and comprise a temperature sensor 12 to measure a temperature TDLV of the service fluid in the delivery duct 5 upstream of the bypass duct 9, a temperature sensor 13 to measure a temperature TRET of the service fluid in the return duct 6 and a sensor 14 to measure a temperature TLIN of the service fluid in the delivery duct 5 downstream of the bypass duct 9, and in particular downstream of the storage tank 10.

[0018] The control system 11 comprises a conventional flow rate sensor 30 to measure the mass flow rate of the hydronic circuit 4 in a point of the return duct 6 downstream of the bypass duct 9. In the following description the letter m is used to indicate said mass flow rate.

[0019] The control system 11 also comprises control means structured on two levels, and in particular high-level control means and low-level control means.

[0020] The high-level control means comprise a supervision unit 15, for example a PC configured to implement a load estimation module 16 suitable to provide an estimation of the thermal load PLE of the hydronic circuit 4 as a function of the temperatures TDLV, TRET and TLIN measured by the sensors 12, 13, 14 and 30 and an optimization module 17 suitable to determine operating state values ST_i and part load ratios PLR_i to set for the refrigerating machines 2 and such as to enable the refrigerating machines 2 to deliver an overall cooling capacity that satisfies the estimated thermal load PLE with minimum electric power consumption. In the following description the term part load refers to a ratio between the cooling capacity requested of the n^{th} refrigerating machine 2 at a certain point of operation and the maximum nominal cooling capacity (PC_{max_i}) of the n^{th} refrigerating machine 2. The operating state ST_i of the n^{th} refrigerating machine can be "on" or "off". In the case of a number N of refrigerating machines 2, the optimization module 17 provides N operating states ST_i and N part load ratios PLR_i , as illustrated in figure 1. The supervision unit 15 is, moreover, configured to implement a calculation module 18 suitable to determine, for each refrigerating machine 2, a respective machine delivery temperature setpoint $TSET_i$ as a function of the estimated thermal load PLE, the temperature TDLV and the part load ratio PLR_i set for said refrigerating machine 2.

[0021] The low-level control means comprise control means 19 to control the switching on and part load operation of the refrigerating machines 2 as a function of the respective operating states ST_i and of the respective setpoints $TSET_i$, set by the supervision unit 15. Thus, given the dependency of the setpoints $TSET_i$ on respective part load ratios PLR_i , the control means 19 are suitable, in general, to control the switching on and part load operation of the refrigerating machines 2 as a function of the respective operating states ST_i and of the respective part load ratios PLR_i .

[0022] Advantageously, as in the example illustrated in the accompanying figure, the control means 19 comprise a plurality of local controllers 20, each of which is connected to a respective refrigerating machine 2 to control the switching on of the refrigerating machine 2 as a function of the set operating state ST_i and control the part load operation of the refrigerating machine 2 as a function of the set setpoint $TSET_i$, and thus as a function of the set part load ratio PLR_i . In particular, each local controller 20 comprises a respective temperature sensor (not illustrated) to measure the local delivery temperature, i.e. the temperature of the service fluid 4 flowing out of the refrigerating machine 2, and is suitable to control the refrigerating machine 2, on the basis of a comparison between the local delivery temperature and a pair of temperature thresholds calculated as a function of the setpoint $TSET_i$, so that said machine 2 delivers a different cooling capacity step in order that the local delivery temperature follows the setpoint $TSET_i$. Each local controller 20 is of a known type and is therefore not described in further detail.

[0023] The load estimation module 16 determines the estimated thermal load PLE by processing the temperatures TDLV, TRET and TLIN using a state observer. The state observer is applied to a dynamic model of the plant 1 in state space form. In particular, the temperatures TDLV, TRET and TLIN are sampled and the dynamic model is shown in state space at discrete points in time.

[0024] The dynamic model, obtained in the case of an adiabatic bypass duct 9 and negligible amounts of service fluid

in the bypass duct 9, enables the thermal load PL to be expressed using the following equation:

$$PL = Cp \cdot \rho \cdot V \cdot \frac{dTLIN}{dt} + m \cdot Cp \cdot (TRET - TDLV),$$

where Cp is the heat exchange coefficient of the service fluid, ρ is the density of the service fluid, V is the volume of service fluid in the part of the hydronic circuit 4 with the convection units 3, i.e. in the part of the hydronic circuit 4 downstream of the bypass duct 9, and m is the mass flow rate of the hydronic circuit 4.

[0025] The dynamics of the thermal load PL are typically slow with respect to those of the refrigerating machines 2. Thus, in the case of a thermal load PL with constant dynamics the dynamic state space model is:

$$\begin{cases} \frac{dPL}{dt} = 0 \\ \frac{dTLIN}{dt} = \frac{1}{\rho \cdot Cp \cdot V} PL + \frac{m}{\rho \cdot V} TDLV - \frac{m}{\rho \cdot V} TRET \end{cases}$$

[0026] Advantageously, the state observer is a Luenberger observer.

[0027] According to an alternative embodiment of the invention, the state observer is a Kalman filter.

[0028] Advantageously, the load estimation module 16 filters the estimated thermal load PLE, before supplying it to the subsequent calculation modules, through a lowpass filter, that is not described, in order to reduce the effects of compressor switching operations (on and off).

[0029] The optimization module 17 determines the operating states ST_i and part load ratios PLR_i by minimizing an objective function OBJ defined as the sum of at least a first and a second term. The first term depends on a difference between the estimated thermal load PLE and a sum of the cooling capacities PC_i delivered by all the refrigerating machines 2. The second term depends on a sum of the electric power PE_i consumed by all the refrigerating machines 2 at the respective cooling capacities PC_i. For example, the objective function OBJ is given by:

$$OBJ = hc \left| \sum_{i=1}^N PC_i - PLE \right|^{kc} + he \left[\sum_{i=1}^N PE_i \right]^{ke},$$

where N is the number of refrigerating machines 2 of the plant 1, hc and kc are respectively a coefficient and an exponent of penalties associated with the thermal load, and he and ke are respectively a coefficient and an exponent of penalties associated with electricity consumption. The penalty coefficient hc is between 5 and 25. The penalty exponent kc is between 0.5 and 2. The penalty coefficient he is between 0.5 and 7. The penalty exponent ke is between 0.5 and 3.

[0030] Each cooling capacity PC_i is defined by the product of a maximum cooling capacity (PC_{maxi}) PC_{maxi} that can be delivered by the respective refrigerating machine 2 multiplied by the part load PLR_i associated with the refrigerating machine 2 and each electric power PE_i is defined by the product of a maximum nominal electric power PEmax_i of the respective refrigerating machine 2 multiplied by a fraction of electric power Z_i corresponding to the part load PLR_i associated with the refrigerating machine 2. For each refrigerating machine 2, the fraction of electric power Z_i is extracted from a curve expressing a ratio between the electric power PE_i consumed and the maximum electric power PEmax_i of the refrigerating machine 2 when the set part load ratio PLR_i changes.

[0031] Figure 2 illustrates an example of a curve expressing the electric power ratio as a function of the part load ratio PLR and of two temperature values T_{air} of the air outside the refrigerating machine (20°C and 35°C). Said curve, indicated in the following description as Z(T_{air}, PLR) has been constructed on the basis of the manufacturer's data for the refrigerating machine 2.

[0032] Thus the objective function OBJ is a function of the part load ratios PLR_i.

$$OBJ(PLR_i) = hc \left| \sum_{i=1}^N [PC \max_i \cdot PLR_i] - PLE \right|^{kc} + he \left[\sum_{i=1}^N PE \max_i \cdot Z_i(PLR_i) \right]^{ke}$$

5

[0033] It is worth noting that, as a general rule, the operating state ST_i can be derived from the value of the corresponding part load ratio PLR_i as follows:

- 10
- if $PLR_i=0$, then $ST_i="off"$;
 - if $PLR_i>0$, then $ST_i="on"$;

[0034] The minimization of the function $OBJ(PLR_i)$ thus returns the best solution of the set of unknown values made up of the plurality of part load ratios PLR_i and operating states ST_i .

15 **[0035]** In order to minimize the objective function $OBJ(PLR_i)$, the optimization module 17 implements a multi-phase optimization algorithm consisting of a multi-phase genetic algorithm acting on individuals defined by potential solutions for operating states ST_i and part load ratios PLR_i and having an fitness index of the individuals defined on the basis of the objective function $OBJ(PLR_i)$.

20 **[0036]** The multi-phase genetic algorithms are of a known type. For this reason only the aspects of the genetic algorithm that affect the invention are described here.

[0037] The set of unknown values for which the best solution is to be found, i.e. all the part load ratios PLR_i and operating states ST_i , is encoded in binary format. Each phase of the genetic algorithm acts on an initial population of solutions (individuals) split into random solutions and the best solutions generated by the previous phase. The first phase is clearly only initialized with random solutions. The population of each phase contains the same number of individuals N_S . During each phase the individuals are recombined to provide a new generation using several operators (reproduction, crossover, mutation, etc.). The total number of generations N_G is preset. The number of phases N_{PH} is defined by the ratio between the number of generations N_G and the number of individuals N_S ($N_{PH} = N_G/N_S$) and the number of generations per phase is defined by the ratio between the number of generations N_G and the number of phases N_{PH} . The number of individuals N_S is between 50 and 300. The number of generations N_G is between 400 and 700.

30 **[0038]** The last phase of the genetic algorithm acts on an initial population of solutions, which comprise solutions implementing a method for controlling the refrigerating machines known as a machine saturation strategy (MS) and solutions implementing a method for controlling the refrigerating machines known as a step saturation strategy (SS). In other words, the initial population of the last phase is divided into randomly-generated solutions, the best solutions generated by the previous phase, solutions implementing the machine control strategy, and solutions implementing the step control strategy. The solutions derived from the known control strategies are inoculated so that the known values can be incorporated into the genetic algorithm which can thus rapidly converge towards a sub-optimal, coherent solution.

35 **[0039]** The initial population is divided into the various solutions described above by means of mixing coefficients, for example according to the following logic. The initial population of each phase that differs from the last phase consists of:

- 40
- $L \cdot N_S$ best solutions from previous phase;
 - $(1-L) \cdot N_S$ random solutions.

[0040] The initial population of the last phase consists of:

- 45
- $L \cdot N_S$ best solutions from previous phase;
 - $(1-L) \cdot L_1 \cdot L_2 \cdot N_S$ solutions according to strategy SS;
 - $(1-L) \cdot L_1 \cdot (1-L_2) \cdot N_S$ solutions according to strategy MS; and
 - $(1-L) \cdot (1-L_1) \cdot N_S$ random solutions.

50 **[0041]** The mixing coefficients L , L_1 and L_2 have respective values of between 0 and 1. Advantageously, each of the mixing coefficients L , L_1 and L_2 is between 0.4 and 0.6.

[0042] The sub-optimal solution in terms of part load ratios PLR_i and operating states ST_i is re-calculated at periodic intervals according to a supervision period lasting from between 10 and 60 minutes.

55 **[0043]** According to an alternative embodiment of the invention, instead of implementing a multi-phase genetic algorithm, the optimization module 17 implements a multi-phase particle swarm optimization algorithm, which acts on particles whose positions in a real multi-dimensional space are defined by potential operating state ST_i and part load ratio PLR_i solutions and has a particle fitness index defined on the basis of the objective function $OBJ(PLR_i)$.

[0044] The particle swarm optimization (PSO) algorithms are of the known type. Therefore only the aspects of the

particle swarm optimization algorithm that affect the invention are described here.

[0045] The set of unknown values for which the best solution is to be found, i.e. all the part load ratios PLR_i and operating states ST_i , are encoded in a known manner. Each phase of the particle swarm algorithm acts on an initial swarm of solutions (particles) divided into random solutions and the best solutions obtained from the previous phase. Clearly the first phase is only initialized with random solutions, i.e. particles with random positions in the multi-dimensional space being considered. The swarm of each phase contains the same number of particles N_S . During each phase the swarm of particles moves and evaluates the objective function $OBJ(PLR_i)$, i.e. the function to be minimized. The number of phases N_{PH} is preset. The number of particles in the swarm N_S is also preset. The number of repetitions for each phase, generally indicated by N_G , is given by the sum of a positive constant and the number of repetitions related to the previous phase, indicated by N_{G-1} . The number of phases N_{PH} is between 1 and 10. The number of particles N_S is between 10 and 100. The number of repetitions N_G is between 10 and 250.

[0046] The last phase of the particle swarm algorithm acts on an initial swarm of solutions, which comprise solutions implementing a machine saturation strategy (MS) to control the refrigerating machines and solutions implementing a step saturation strategy (SS) to control the refrigerating machines. In other words, the initial swarm of the last phase is divided into randomly-generated solutions, the best solutions generated by the previous phase, solutions implementing the machine control strategy, and solutions implementing the step control strategy. The solutions derived from the known control strategies are inoculated so that the known values can be incorporated into the particle swarm algorithm which can thus rapidly converge towards a sub-optimal, coherent solution.

[0047] The initial swarm is divided into the various types of solutions mentioned above by means of mixing coefficients, for example in the manner described previously for the genetic algorithm.

[0048] As with the genetic algorithm, the sub-optimal solution in terms of part load ratios PLR_i and operating states ST_i is re-calculated at periodic intervals according to a supervision period lasting from between 10 and 60 minutes.

[0049] The calculation module 18 comprises a temperature setpoint estimation module 21 to calculate, for each refrigerating machine 2, an intermediate setpoint $TSETM_i$ as a function of the estimated thermal load PLE , the temperature $TDLV$ and the part load ratio PLR_i set for the refrigerating machine 2. For example, the intermediate setpoint $TSETM_i$ is calculated using the following formula:

$$TSETM_i = TDLV + \Delta T_0 \cdot \left(\frac{PLE}{PCP_{max}} - PLR_i \right),$$

where ΔT_0 is a plant parameter expressing a desired difference between the delivery and return temperatures and PCP_{max} is the maximum nominal cooling capacity (PC_{maxi}) of the plant 1.

[0050] The calculation module 18 also comprises: a subtraction module 22 to calculate an error ERR as the difference between a preset plant delivery temperature setpoint $TSETP$ and the measured temperature $TLIN$; a PID (proportional-integral-derivative) controller 23, which is known in the prior art and is not described in detail here, to determine a correction factor $\Delta TSET$ as a function of the error ERR ; and an addition module 24 to calculate the setpoint $TSET_i$ of each refrigerating machine 2 as the sum of the respective intermediate setpoint $TSETM_i$ and the correction factor $\Delta TSET$.

[0051] The purpose of the PID controller 23 is to reduce inaccuracies in the calculation of the temperature $TLIN$ after long periods of operation of the plant 1 and due to the approximations introduced by the curves $Z(T_{air}, PLR)$.

[0052] According to an alternative embodiment of the invention that is not illustrated, the calculation module 18 comprises an error estimation module, instead of the subtraction module 22, to calculate the error ERR using a non-linear function of the setpoint $TSETP$ and of the temperature $TLIN$.

[0053] According to a further alternative embodiment of the invention that is not illustrated, the calculation module 18 comprises a combination module, instead of the addition module 24, to calculate the setpoint $TSET_i$ using a non-linear function of the intermediate setpoint $TSETM_i$ and of the correction factor $\Delta TSET$.

[0054] The main advantage of the method and of the system for controlling a plurality of refrigerating machines of an air-conditioning plant described above is that it allows the refrigerating machines to be used as close as possible to their peak efficiency level while reducing electric power consumption to a minimum, the delivery of overall cooling capacity being equal. Moreover, the implementation of a multi-phase genetic algorithm at supervision level makes it possible to rapidly converge towards a sub-optimal, coherent solution to the problem of minimization.

Claims

1. A method for controlling a plurality of refrigerating machines (2) of an air-conditioning plant (1) comprising convection means (3) connected to the refrigerating machines (2) via a service circuit (4), which comprises a delivery duct (5)

within which the service fluid flows from the refrigerating machines (2) to the convection means (3), a return duct (6) within which the service fluid flows in the opposite direction and a bypass duct (9) connecting a point (5a) on the delivery duct (5) and a point (6a) on the return duct (6); the method **being characterized in that it** comprises:

- measuring, by temperature sensing means (12-14), a first temperature (TDLV) of the service fluid in the delivery duct (5) upstream of the bypass duct (9), a second temperature (TRET) of the service fluid in the return duct (6), and a third temperature (TLIN) of the service fluid in the delivery duct (5) downstream of the bypass duct (9);
- determining an estimation of the thermal load (PLE) of the service circuit (4) as a function of said first, second and third temperature (TDLV, TRET, TLIN);
- determining operating states (ST_i) and part load ratios (PLR_i) to set for the refrigerating machines (2) such as to allow the refrigerating machines (2) to deliver an overall cooling capacity that satisfies the estimated thermal load with the minimum consumption of electric power; and
- controlling the switching on and part load operation of the refrigerating machines (2) as a function of the respective operating states (ST_i) and part load ratios (PLR_i).

2. The method according to claim 1, wherein said operating states (ST_i) and part load ratios (PLR_i) to set for the refrigerating machines (2) are determined by minimizing an objective function (OBJ) defined by a sum of at least a first and a second term, the first term depending on a difference between the estimated thermal load (PLE) and a sum of the cooling capacities (PC_i) delivered by all the refrigerating machines (2), the second term depending on a sum of the electric powers (PE_i) consumed by all the refrigerating machines (2) at the respective cooling capacities (PC_i).

3. The method according to claim 2, wherein each of said cooling capacities (PC_i) is defined by the product of a maximum cooling capacity ($PC_{max,i}$) that can be delivered by the respective refrigerating machine (2) multiplied by the part load ratio (PLR_i) associated with the refrigerating machine (2) and each of said electric powers (PE_i) is defined by the product of a maximum nominal electric power ($PE_{max,i}$) of the respective refrigerating machine (2) multiplied by a fraction of electric power (Z_i) corresponding to the part load ratio (PLR_i) associated with the refrigerating machine (2).

4. The method according to claim 2 or 3, wherein said objective function (OBJ) is minimized by means of a multi-phase optimization algorithm consisting of a multi-phase genetic algorithm, which acts on individuals defined by potential operating state (ST_i) and part load ratio (PLR_i) solutions and has a fitness index of the individuals defined on the basis of the objective function (OBJ), or by a multi-phase particle swarm algorithm, which acts on particles defined by potential operating state (ST_i) and part load ratio (PLR_i) solutions and has a fitness index of the particles defined on the basis of the objective function (OBJ).

5. The method according to claim 4, wherein the last phase of said multi-phase optimization algorithm acts on an initial set of solutions, which comprise first solutions implementing a machine saturation strategy to control the refrigerating machines (2) and second solutions implementing a step saturation strategy to control the refrigerating machines (2).

6. The method according to any of the claims from 1 to 5, further comprising:

- determining, for each refrigerating machine (2), a respective machine delivery temperature setpoint ($TSET_i$) as a function of said estimated thermal load (PLE), said first temperature (TDLV) and the part load ratio (PLR_i) set for the refrigerating machine (2);
- said part load operation of the refrigerating machines (2) being controlled as a function of the respective machine delivery temperature setpoints ($TSET_i$).

7. The method according to claim 6, wherein determining, for each refrigerating machine (2), a respective machine delivery temperature setpoint ($TSET_i$) comprises:

- calculating an intermediate setpoint ($TSETM_i$) as a function of said estimated thermal load (PLE), said first temperature (TDLV) and said part load value (PLR_i) set;
- calculating an error (ERR) as a function of said third temperature (TLIN) and of a preset plant delivery temperature setpoint;
- determining a correction factor ($\Delta TSET$) as a function of said error (ERR) by means of a proportional-integral-derivative control; and
- calculating the machine delivery temperature setpoint ($TSET_i$) as a function of the intermediate setpoint ($TSETM_i$).

M_i) and the correction factor ($\Delta TSET$).

- 5 8. A control system for controlling a plurality of refrigerating machines (2) of an air-conditioning plant (1) comprising convection means (3) connected to the refrigerating machines (2) via a service circuit (4), which has a delivery duct (5) within which a service fluid flows from the refrigerating machines (2) to the convection means (3), a return duct (6) within which a service fluid flows in the opposite direction and a bypass duct (9) connecting a point (5a) on the delivery duct (5) and a point (6a) on the return duct (6); the control system (11) **being characterized in that it** comprises: temperature sensing means (12-14) arranged along the service circuit (4) to measure a first temperature (TDLV) of the service fluid in the delivery duct (5) upstream of the bypass duct (9), a second temperature (TRET) of the service fluid in the return duct (6) and a third temperature (TLIN) of the service fluid in the delivery duct (5) downstream of the bypass duct (9); supervision means (15), configured to implement a load estimation module (16) to provide an estimation of the thermal load (PLE) of the service circuit (4) as a function of said first, second and third temperature (TDLV, TRET, TLIN) and an optimization module (17) to determine operating states (ST_i) and part load ratios (PLR_i) to set for the refrigerating machines (2) such as to enable the refrigerating machines (2) to deliver an overall cooling capacity that satisfies the estimated thermal load (PLE) with the minimum electric power consumption; and control means (19) to control the switching on and part load operation of the refrigerating machines (2) as a function of the respective operating states (ST_i) and part load ratios (PLR_i).
- 10 9. The control system according to claim 8, wherein said optimization module (17) is suitable to determine said operating states (ST_i) and part load ratios (PLR_i) by minimizing an objective function (OBJ) defined as the sum of terms that depend on a sum of the cooling capacities (PC_i) delivered by all the refrigerating machines (2), on said estimated thermal load (PLE) and on a sum of the electric powers (PE_i) consumed by all the refrigerating machines (2) at the respective cooling capacities (PC_i).
- 15 10. The control system according to claim 9, wherein said optimization module (17) implements a multi-phase optimization algorithm consisting of a multi-phase genetic algorithm, which acts on individuals defined by potential operating state (ST_i) and part load ratio (PLR_i) solutions and has a fitness index of the individuals defined on the basis of said objective function (OBJ) to be minimized, or by a multi-phase particle swarm algorithm, which acts on particles defined by potential operating state (ST_i) and part load ratio (PLR_i) solutions and has a fitness index of the particles defined on the basis of the objective function (OBJ).
- 20 11. The control system according to any of the claims from 8 to 10, wherein said supervision means (15) are configured to implement a calculation module (18) suitable to determine, for each refrigerating machine (2), a respective machine delivery temperature setpoint ($TSET_i$) as a function of said estimated thermal load (PLE), said first temperature (TDLV) and the part load ratio (PLR_i) set for the refrigerating machine (2); said control means (19) being configured to control the part load operation of the refrigerating machines (2) as a function of the respective machine delivery temperature setpoints ($TSET_i$).
- 25 12. The control system according to claim 11, wherein said control means (19) comprise a plurality of local controllers (20), each of which is connected to a respective refrigerating machine (2) to control the part load operation of said refrigerating machine (2) as a function of the respective machine delivery temperature setpoint ($TSET_i$).
- 30 13. The control system according to claim 11 or 12, wherein said calculation module (18) comprises a proportional-integral-derivative control module (23) to determine a correction factor ($\Delta TSET$) as a function of an error (ERR), which is calculated as a function of said third temperature (TLIN) and of a preset plant delivery temperature setpoint ($TSETP$); the calculation module (18) being configured to determine each said machine delivery temperature setpoint ($TSET_i$) as a function of the correction factor ($\Delta TSET$).
- 35 14. An air-conditioning plant comprising: a plurality of refrigerating machines (2); convection means (3) connected to the refrigerating machines (2) via a service circuit (4), which has a delivery duct (5) within which a service fluid flows from the refrigerating machines (2) to the convection means (3), a return duct (6) within which the service fluid flows in the opposite direction and a bypass duct (9) connecting a point (5a) on the delivery duct (5) and a point (6a) on the return duct (6); and a control system (11) for controlling the refrigerating machines (2); the air-conditioning plant (1) **being characterized in that** the control system (11) is of the type disclosed in any one of the claims from 8 to 13.

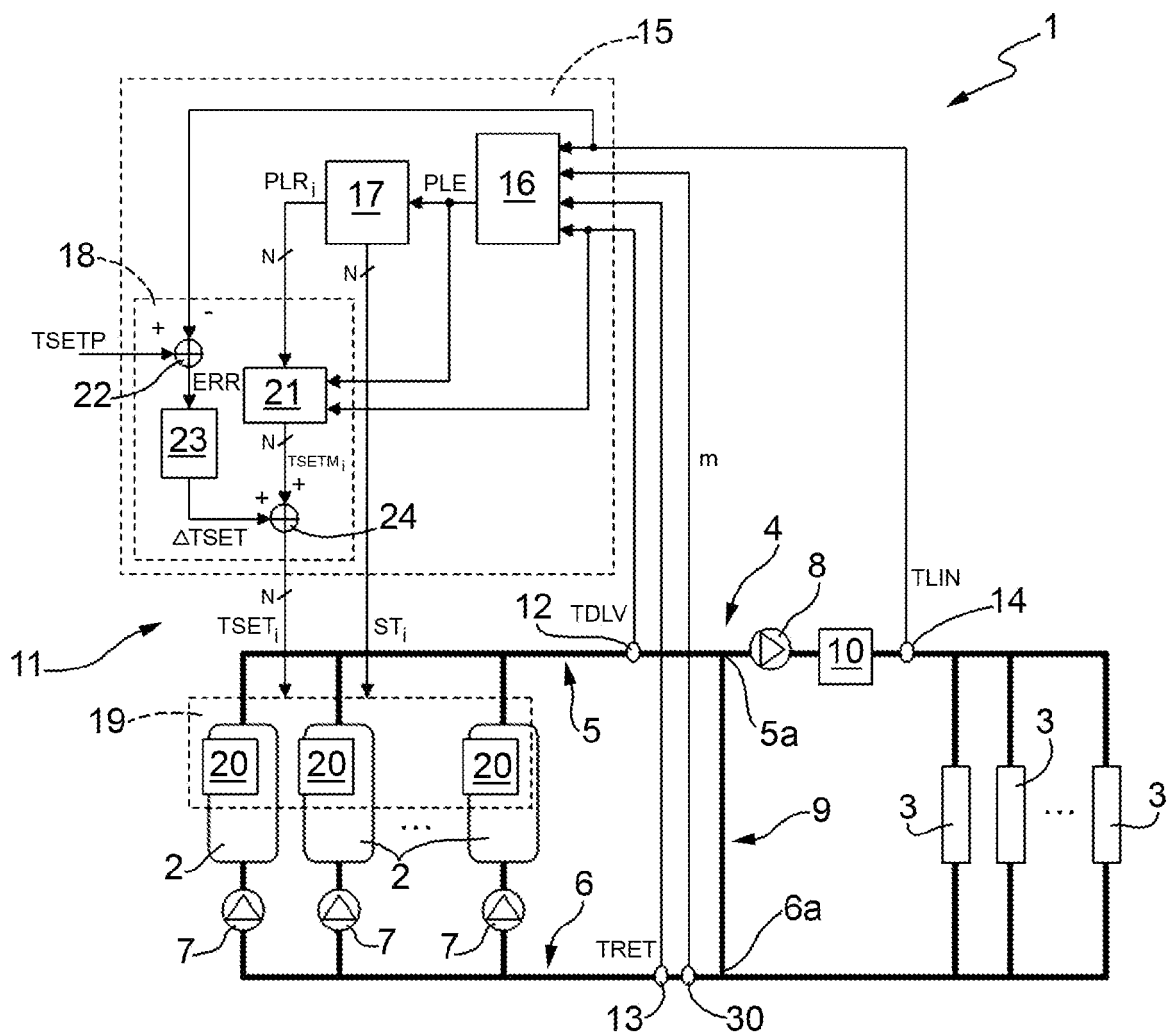


FIG.1

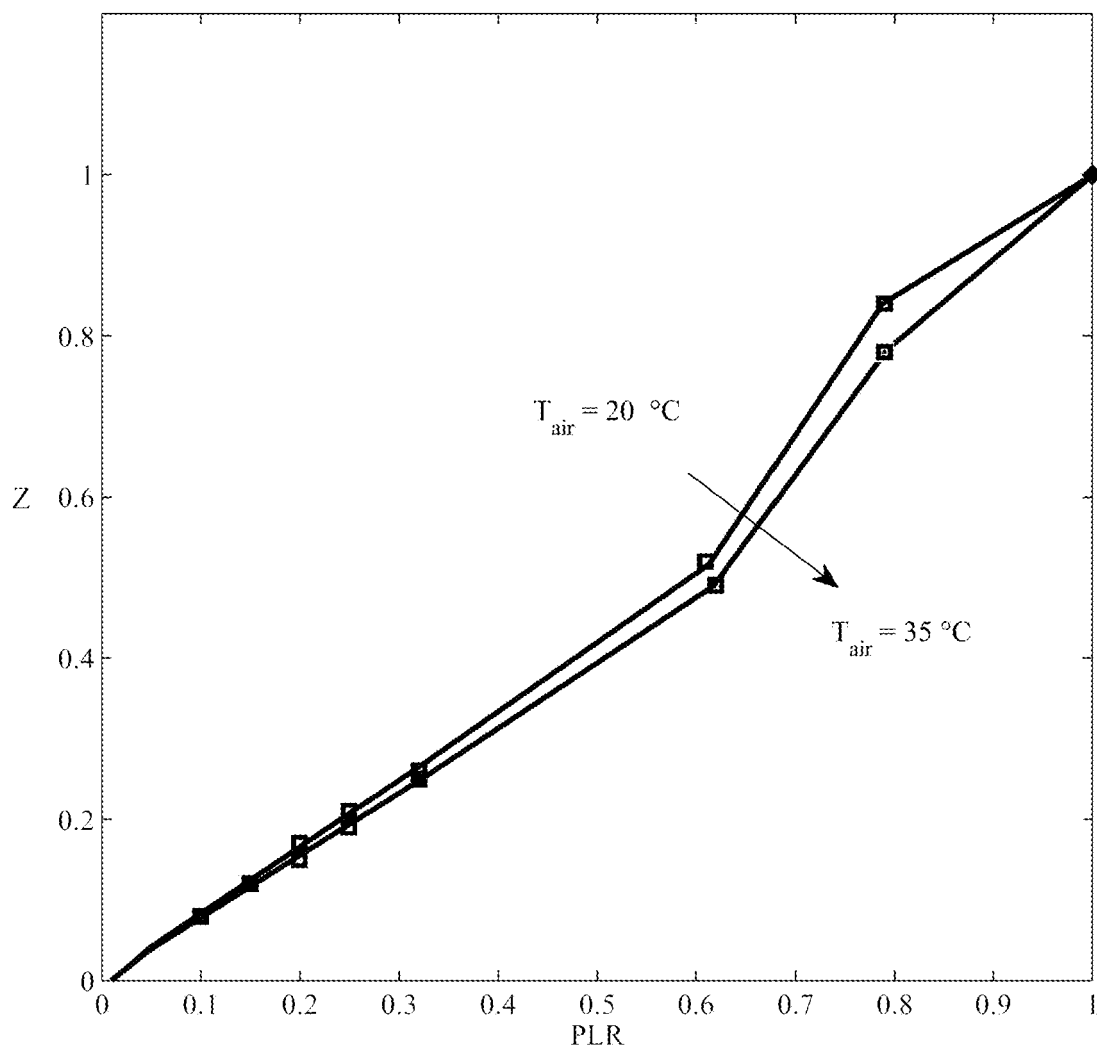


FIG.2



EUROPEAN SEARCH REPORT

Application Number
EP 10 16 2899

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			F24F F25B
Place of search		Date of completion of the search	Examiner
Munich		8 September 2010	Valenza, Davide
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 10 16 2899

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