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(54) A Distributed Cooperative Control Method for Optimizing a DC Power Grid

(57) The present invention discloses a distributed cooperating control method for optimizing a DC power grid, in particular a distributed algorithm based on coordination descent, which can perform multiple-objective optimization, i.e., energy loss reduction and voltage adjustment. The method includes establishing a multi-objective optimization mathematical model for the DC power grid to prove that the multi-objective optimization problem is a convex optimization problem, and a distributed algorithm based on coordinate descent is designed to solve the problem. According to the method, it is unnecessary to use the line impedance during finding the optimization results, so that deviation to the optimization results caused by fluctuation of network parameters can be avoided, and the optimal economical operation point of the system can be automatically found.

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A Distributed Cooperative Control Method for Optimizing a DC Power Grid

Technical Field

The present invention relates to the technical field of DC power system, in particular to power flow optimization and voltage adjustment of a grand power grid, and more particularly, to a distributed cooperative control method for optimizing a DC power grid.

Technical Background

With the rapid development of power electronics technology, the DC power system including power electronic equipment acting as a core role has regained people's attention. Compared with the AC power grid, the DC power grid has the following advantages. In the aspect of distributed power generation, there is no need for redundant power conversion, thus enjoying less energy loss and simple control. In the aspect of power transmission, there is no constraint for power angle stability, thus significantly reducing both of line cost and line loss. In the aspect of power distribution, there is no need for phase frequency control, thus improving the ability of accommodating distributed sources and effectively coordinating the conflicts between renewable energy sources and the grand power grid. In the aspect of power consumption, it is flexible in control, rapid in response, and able to supply high quality of energy and meet increasingly diverse load requirements. Therefore, the DC power system has been more and more widely used.

Power flow optimization and voltage regulation are hot issues in power system research. Specifically, due to the existence of the transmission line impedance, the power loss will seriously affect the economical operation of the system. At the same time, the voltage deterioration caused by the line impedance may cause abnormal operation of the load, thus threatening safety and applicability of the equipment. In order to solve these problems, many studies have been conducted.

Most existing control methods adopt a centralized manner, which relies on computers of high band width communication and high performance. This will lead to high communication cost, single point of failure, and further limit the plug-and-play function of the system. In contrast, the distributed algorithm can achieve global information transmission through low band width communication, thus reducing communication cost. However, the distributed control method currently used needs to obtain information such as line impedance, which is difficult to measure. In addition, the impedance value is easily changed due to the operation state and weather conditions, so that the system operation will operate under a condition which is deviated from the optimal point.

Summary of the Invention

In order to solve the above-mentioned problem, the present invention aims to provide a distributed cooperative control method for optimizing a DC power grid, so as to solve the problems of network loss and voltage adjustment in the DC power grid. According to the present method, each time the voltage of only one power supply node is adjusted, thus avoiding failure caused by regulating multiple power supplies at the same time. Moreover, computation of the present method is less complex, thus reducing the requirement on computer performance.

The present invention proposes a distributed cooperative control method for optimizing a DC power grid. Specifically, this method is a distributed cooperative control method for network loss reduction and voltage adjustment. The control method includes:

a) enabling a topology of a mesh-like DC power system, which contains *n* power supply nodes and m load nodes, to be equivalent to a graph based on graph theory, to obtain a corresponding admittance matrix of a power transmission network as follows:

$$Y=\begin{pmatrix} Y_{SS} & Y_{SL} \\ Y_{LS} & Y_{LL} \end{pmatrix},$$

and obtain, according Ohm's Law, current $[I_S, I_L]^T$ flowing to the power transmission network from each node, wherein I_S is output current from a power supply node, and I_L is current flowing to the power transmission network from a load node;

b) setting a performance index J_1 on line loss optimization and a performance index J_2 on voltage adjustment, and establishing a multiple-objective optimal problem, wherein

$$J_1=U_S^T I_S+U_L^T I_L,$$

$$J_2=\|U_L-U_N\|_2^2,$$

$$J=\alpha J_1+\beta J_2, \text{ wherein } \alpha+\beta=1,\ \alpha\geq 0,\ \beta\geq 0,$$

in which U_S is output voltage from the power supply node, U_L is voltage flowing to the power transmission network from a load node, and U_N is rated load voltage; and

c) solving said optimal problem through an improved distributed algorithm based on coordination descent, wherein the distributed algorithm includes steps of:

step 1: setting current step size $d=d_0$, output voltage $U_s=U_S^0$, number of iterations $i=0$, and power supply node number $p=1$, wherein d_0 is an initial step size, U_S^0 is an initial voltage value, and adjusting a power of a first power supply;

step 2: collecting load power, power node power, and load voltage for feedback control, but not measuring a line impedance that is difficult to determine, and setting $i=i+1$;

step 3: calculating $\alpha J_1+\beta J_2$, which is recorded as $P_{\_ob}(i-1)$;

step 4: adding a voltage step disturbance into a current power supply node voltage $V_{sp}{}^{i}$, i.e., $V_{sp}{}^{i}=V_{sp}{}^{i-1}+d$, and keeping other node voltages unchanged;

step 5: recalculating $\alpha J_1+\beta J_2$, which is recorded as $P_{\_ob}(i)$;

step 6: comparing $P_{\_ob}(i)$ with $P_{\_ob}(i-1)$;

step 7: changing, when $|P_{\_ob}(i)-P_{\_ob}(i-1)|<\varepsilon$, the initial value of the current power supply, $i=0$, $d=d_0$, $V_{sp}{}^{0}=V_{sp}{}^{i-1}$, selecting $p+1$,and going to step 2;

step 8: otherwise, determining whether $P_{\_ob}(i)-P_{\_ob}(i-1)$ is true; if yes, setting $d=1.1d$ and then going to step 2; if not, performing step 9; and

step 9: setting $d=-d_0$, and going to step 2.

In an embodiment, the performance index J_1 is specifically indicated as the follows:

$$J_1 = U_S^T (Y_{SS} + Y_{SL}A + A^T Y_{LS} + A^T Y_{LL} A) U_S ,$$

wherein $A = -(Y_{LL} + [Y_{Load}])^{-1} Y_{LS}$, in which Y_{Load} is admittance of the load, and Y_{SS}, Y_{SL}, Y_{LS} and Y_{LL} are elements in the admittance matrix Y, respectively.

In an embodiment, the performance index J_2 is specifically indicated as the follows:

$$J_2 = U_S^T A^T A U_S - 2U_N^T A U_S + U_N^T U_N .$$

In an embodiment, since the global information is necessary in the iteration procedure, the distributed control algorithm is used instead of centralized communication. According to follow-lead algorithm of the distributed control algorithm, the power supply nodes are divided as master nodes and slave nodes, each master nodes collecting information of adjacent loads and then transmitting it to slave nodes,

$$\begin{cases} \dot{V}_{Li}^{(i)} = \sum_{l=1}^{k} a_{ij} (V_{Ll}^{(l)} - V_{Li}^{(i)}), & \forall i \in N - \Omega \\ \dot{P}_{Li}^{(i)} = \sum_{l=1}^{k} a_{ij} (P_{Ll}^{(l)} - P_{Li}^{(i)}), & \forall i \in N - \Omega \\ \dot{P}_{si}^{(i)} = \sum_{l=1}^{k} a_{ij} (P_{sl}^{(l)} - P_{si}^{(i)}), & \forall i \in N - \Omega \end{cases}$$

wherein: Ω is a collection of master nodes; N is a total number of power supply nodes; V_{Li}, P_{Li}, and P_{si} are load node voltage information, load node power information, and power supply node power information received from a node, respectively; V_{Ll}, P_{Ll}, and P_{sl} are load node voltage information, load node power information, and power supply node power information of a neighbor node, respectively; and a_{ij} is a weighting coefficient of a communication network, in which a_{ij}=1 when an i^{th} power supply is in data communication with a j^{th} power supply, otherwise a_{ij}=0. In this manner, global information sharing can be achieved.

The distributed cooperating control method according to the present invention proposes a distributed algorithm based on coordination descent, which can perform multiple-objective optimization, i.e., energy loss reduction and voltage adjustment. In particular, the distributed algorithm includes establishing a multi-objective optimization mathematical model for the DC power grid to prove that the multi-objective optimization problem is a convex optimization problem. Therefore, based on the features of the convex optimization model, a distributed algorithm based on coordinate descent is designed to solve the problem. According to the present method, it is unnecessary to use the line impedance during finding the optimization results, so that deviation to the optimization results caused by fluctuation of network parameters can be avoided, and the optimal economical operation point of the system can be automatically found. According to the present method, in practical applications, each time the voltage of only one single power supply node is adjusted, thus achieving the cooperating control of the distributed control. This can avoid failures caused by simultaneous adjustment of multiple power supplies, reduce the complex of computation and requirements on computer performance.

Brief Description of the Drawings

Fig. 1 is an equivalent topology diagram of a DC power grid according to the present invention;

Fig. 2 is a flow chart of iterative procedure of a distributed algorithm according to the present invention;

Fig. 3 shows a simulation diagram of Example 1;

Fig. 4 shows a simulation diagram of Example 2;

Fig. 5 shows a simulation diagram of Example 3; and

Fig. 6 shows a simulation diagram of Example 4.

Detailed Description of the Invention

The present invention will be described in further detail with reference to preferred embodiments in combination with the accompanying drawings. The following embodiments are merely used for illustration, but not for limiting the scope of the present invention.

To maintain the system operating in the optimal point, the present invention proposes a multi-objective optimal solution with respect to the line loss and voltage adjustment, and thus provides a distributed algorithm based on coordinate descent. The distributed cooperative control method for the DC power grid optimization according to the present invention includes the following steps.

Considering a mesh-like DC power distribution system containing n power supply nodes (e.g., transformers) and m load nodes, the topology of the DC distribution system can be equivalent to a graph by using graph theory. Therefore, a corresponding admittance matrix of a power transmission network is obtained as follows:

$$Y = \begin{pmatrix} Y_{SS} & Y_{SL} \\ Y_{LS} & Y_{LL} \end{pmatrix}.$$

According to Ohm's law, current $[I_S, I_L]^T$ flowing to the transmission network from each node is obtained, wherein I_S is output current of a power supply node, and I_L is current flowing to the transmission network from a load node.

The line loss can be calculated through the following equation:

$$J_1 = U_S^T I_S + U_L^T I_L \qquad (1)$$

The index on the load voltage is defined as follows:

$$J_2 = \|U_L - U_N\|_2^2 \qquad (2)$$

The multi-objective optimal problem is defined as follows:

$$J = \alpha J_1 + \beta J_2 \qquad (3)$$

The relation between the voltage and the current of a node is as follows:

$$I = YU \qquad (4)$$

This can be represented in form of a matrix as follow:

$$\begin{bmatrix} I_S \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{SS} & Y_{SL} \\ Y_{LS} & Y_{LL} \end{bmatrix} \begin{bmatrix} U_S \\ U_L \end{bmatrix} \quad (5)$$

The relation between the power and the voltage is represented as follows:

$$\begin{cases} P_S = [U_S]Y_{SS}U_S + [U_S]Y_{SL}U_L \\ P_L = [U_L]Y_{LS}U_S + [U_L]Y_{LL}U_L \end{cases} \quad (6)$$

In resistance load characteristic, assuming the load impedance R_{Load} to be $R_{Load} = [R_{L1}...R_{Li}...R_{Ln}]^T$, the following can be obtained according to Ohm's law:

$$P_L = -[U_L][Y_{Load}]U_L \quad (7)$$

wherein, Y_{Load} is admittance of the load, Y_{SS}, Y_{SL}, Y_{LS} and Y_{LL} are elements in the admittance matrix Y respectively, and U_N is rated load voltage (which is set as 300V in the following). Considering equations (6) and (7), the load voltage can be represented as follows:

$$U_L = -(Y_{LL} + [Y_{Load}])^{-1} Y_{LS} U_S \quad (8)$$

Defining $A = -(Y_{LL} + [Y_{Load}])^{-1} Y_{LS}$, and combining equations (6) and (8) into equation (1), the following equation can be obtained:

$$J_1 = U_S^T (Y_{SS} + Y_{SL}A + A^T Y_{LS} + A^T Y_{LL} A) U_S \quad (9)$$

Combining equation (8) into equation (2), the following equation can be obtained:

$$J_2 = U_S^T A^T A U_S - 2U_N^T A U_S + U_N^T U_N \quad (10)$$

Combining equation (9) and (10) into equation (3), the following equation can be obtained:

$$\begin{aligned} J = U_S^T (&\alpha Y_{SS} + \alpha Y_{SL} A + \alpha A^T Y_{LS} + \alpha A^T Y_{LL} A \\ &+ \beta A^T A) U_S - 2\beta U_N^T A U_S + \beta U_N^T U_N \end{aligned} \quad (11)$$

Based on non-negative of the performance index and the characteristic of quadratic, it can be readily concluded that J is a convex problem.

Therefore, the multi-objective optimization problem to be solved can be described as follows:

$$\min_{U_S} J(U_S) \qquad (12)$$

The global optimal solution for equation (12) is as follows:

$$U_S^* = \beta(\alpha Y_{SS} + \alpha Y_{SL}A + \alpha A^T Y_{LS} + \alpha A^T Y_{LL} A + \beta A^T A)^{-1} A U_N \qquad (13)$$

In order to solve equation (12), the following distributed algorithm based on coordination descent is presented, mainly including two parts.

A. the distributed algorithm based on improved coordination descent

The optimization method based on coordinate descent is a cost-effective method. In each iteration, the voltages of other power supplies remain unchanged, thus avoiding the risk of grid voltage collapse caused by simultaneous regulation of multiple power supplies. Therefore, the multiple-variable optimization problem is transformed into a one-variable optimization problem. The specific procedure thereof is shown in Fig. 2.

Specifically, the distributed algorithm employed in Fig. 2 includes the following steps:

step 1: setting current step size $d=d_0$, output voltage $U_s=U_S^0$, number of iterations i=0, and power supply node number p=1, wherein d_0 is an initial step size, U_S^0 is an initial voltage value, and adjusting a power of a first power supply;

step 2: collecting load power, power node power, and load voltage for feedback control, but not measuring a line impedance, and setting $i=i+1$;

step 3: calculating $\alpha J_1+\beta J_2$, which is recorded as $P_{\_ob}(i-1)$;

step 4: adding a voltage step disturbance into a current power supply node voltage $V_{sp}^{\ i}$, i.e., $V_{sp}^{\ i} = V_{sp}^{\ i-1} + d$, and keeping other node voltages unchanged;

step 5: recalculating $\alpha J_1+\beta J_2$, which is recorded as $P_{\_ob}(i)$;

step 6: comparing $P_{\_ob}(i)$ with $P_{\_ob}(i\text{-}1)$;

step 7: changing, when $|P_{\_ob}(i)\text{-}P_{\_ob}(i\text{-}1)|<\varepsilon$, the initial value of the current power supply, i=0, d=d_0, $V_{sp}{}^{0}$=$V_{sp}{}^{i\text{-}1}$, selecting p+1,and going to step 2;

step 8: otherwise, determining whether $P_{\_ob}(i)\text{-}P_{\_ob}(i\text{-}1)$ is true; if yes, setting d = 1.1d and then going to step 2; if not, performing step 9; and

step 9: setting d=-d_0, and going to step 2.

In the entire optimization procedure, it is unnecessary to know the information about the line impedance. No matter how the line impedance or the load changes, it can be ensured that the power system can always operate under the optimal operation point.

B. the distributed algorithm on global information estimation

In order to better implement the algorithm based on coordinate descent, each power agent needs to collect the voltage and power of the load node, and the output power of other power nodes. Since the information is obtained by a local sensor installed at each node, the easiest way for information transmission is to broadcast it to all other agents. However, this will lead to an increase in communication cost, and is undesirable for the scalability of a large-scale distributed system. Therefore, in the present invention a distributed algorithm is adopted for global information transmission. In fact, the information about the voltage and power of each load node only needs to be transmitted to at least one agent adjacent to said power node. The agent is called master agent, and a collection of all master agents is expressed as Ω. In order to broadcast this information to all other agents, the master agent repairs the information, and the slave agent should update its value as:

$$\begin{cases} \dot{V}_{Li}^{(i)} = \sum_{l=1}^{k} a_{ij}(V_{Ll}^{(l)} - V_{Li}^{(i)}), & \forall i \in N - \Omega \\ \dot{P}_{Li}^{(i)} = \sum_{l=1}^{k} a_{ij}(P_{Ll}^{(l)} - P_{Li}^{(i)}), & \forall i \in N - \Omega \\ \dot{P}_{si}^{(i)} = \sum_{l=1}^{k} a_{ij}(P_{sl}^{(l)} - P_{si}^{(i)}), & \forall i \in N - \Omega \end{cases}$$

wherein: N is a total number of power supply nodes; V_{Li}, P_{Li}, and P_{si} are voltage information of load node, power information of load node, and power information of the power supply node received from a node, respectively; V_{Ll}, P_{Ll}, and P_{sl} are voltage information of the load node, power information of load node, and power information of power supply node of a neighbor node, respectively; and a_{ij} is a weighting coefficient of a communication network, in which $a_{ij}=1$ when an i^{th} power supply is in data communication with a j^{th} power supply, otherwise $a_{ij}=0$. In this way, sharing global information is achieved.

Finally, in order to illustrate the practical effect of the above control method, the present invention provides a DC power distribution system, which comprises 6 power supply nodes and 14 load nodes, as shown in Fig. 1. In this figure, black nodes represent power supply nodes, dark gray nodes represent load nodes, light gray nodes represent intelligent nodes, and numbers represent line labels. The load impedance values are: $R_{load}=[R_{l1}...R_{li}...R_{l14}]^T=[10, 15, 20, 20, 20, 10, 30, 40, 10, 13, 13, 20, 20]\Omega$, and the line impedance values are: $R_{line}=[R_{line1}...R_{linei}, R_{line19}]=[0.3, 0.1, 0.2, 0.1, 0.3, 0.3, 0.1, 0.2, 0.2, 0.3, 0.4, 0.3, 0.5, 0.3, 0.4, 0.2, 0.4, 0.1, 0.1]\Omega$. The rated load voltage is 300V, and the initial value of the power supply voltage is 302V.

Example 1: the weighing coefficient $\alpha=0.1$ and $\beta=0.9$, and the initial optimized step size $d_0=0.1$V.

Example 2: the weighing coefficient $\alpha=0.1$ and $\beta=0.9$, and the impedance values of load nodes 2, 4, 9 and 13 are changed to 7.5Ω, 10Ω, 20Ω and 10Ω from 15Ω, 20Ω, 40Ω and 20Ω, respectively, after t=100s.

Example 3: the weighing coefficient $\alpha=0.15$ and $\beta=0.85$, and the line impedances R_{line5}, R_{line6}, R_{line17} are changed to 0.15Ω, 0.2Ω, and 0.2Ω from 0.3Ω, 0.3Ω, and 0.4Ω, respectively, after t=70s.

Example 4: the weighing coefficient $\alpha=0.15$ and $\beta=0.85$. The power supply node 7 is operated independent of the system at the beginning. After t=80s, the power supply node 7 is connected to the load node 11, and the connecting line impedance is 0.3Ω. After t=160s, the load node is separated from the system and operated independently.

Figs. 3-6 show the simulation results of Example 1 to Example 4, which respectively include the simulation curves of target value, power supply voltage and load voltage.

The result of Example 1 is shown in Fig. 3. The target value curve a-1 of Fig. 3 indicates that the control method can converge to the optimal target value. The power supply voltage curve a-2 of Fig. 3 indicates that the power nodes change their output voltages in turn, in order to reduce the target value. The load voltage curve a-3 of Fig. 3 indicates that all voltages at the load nodes are close to 300V. Since the remote load nodes are not directly connected to the power supply nodes, there is a voltage drop on the transmission line between the load nodes, so that it is impossible for all load nodes to reach 300V.

Similarly, the result of Example 2 is shown in Fig. 4. After t=100s, when the load changes, the proposed control method can automatically detect the change of the load, so as to find the optimal solution of the system under the new state.

The result of Example 3 is shown in Fig. 5. Without measuring the line impedance, the system can automatically operate under a new optimal point according to the proposed control method.

The result of Example 4 is shown in Figure 6. When a new power supply node is connected to the system, the realization of plug-and-play capability is especially important in a large DC power system. In this case, the present invention verifies the plug-and-play performance of the method. The power node 7 operates independently of other nodes before t=80s. When t=80s, the node 7 is connected to the load node 11, with a line impedance of 0.3. At the same time, the node 7 is in data communication with the power supply nodes 5 and 6. When t=160s, the load node 11 is disconnected from the entire system. As can be seen from Fig. 1, during the insertion and removal of the power supply node 7 and of the load node 11, the voltage of the power supply node is continuously adjusted, indicating that the control method has good plug-and-play performance.

It should be pointed out that the above-mentioned multi-objective optimization problem of network loss reduction and voltage adjustment and the distributed algorithm based on coordinate descent include establishing a multi-objective optimization mathematical model of a DC power grid to prove that the multi-objective optimization problem is a convex optimization problem. On this basis, a distributed algorithm based on coordinate descent is designed to solve the problem. The control method does not need to know the information about the line impedance during the optimization process, so that the deviation to the optimal solution caused by the fluctuation of the network parameters can be avoided, and the optimal economic operation point of the system can be automatically found. In practical applications, the control method only adjusts the voltage of one single power supply node at a time, thus avoiding the adjustment failure caused by simultaneous adjustment of multiple power supplies. The method has low computational complexity and puts low requirements on computer performance.

The above description of specific embodiments of the present invention has been described with reference to the accompanying drawings, but is not intended to limit the scope of the invention. Other different forms of modifications or variations may be made by those skilled in the art in light of the above description. There is no need and no way to exhaust all of the implementation modes. On the basis of the technical solutions of the present invention, various modifications or variations that can be made by those skilled in the art without any creative effort are still within the scope of the present invention.

Conclusies

1. Een gedistribueerde coöperatieve regelmethode voor het optimaliseren van een DC vermogensnetwerk, omvattende stappen van:
a) het in staat stellen van een topologie van een netwerkachtig DC vermogenssysteem dat n vermogenstoevoerknooppunten en m belastingsknooppunten omvat, dat equivalent is aan een graaf voor het verkrijgen van een corresponderende admittantiematrix van een vermogensoverdrachtnetwerk als volgt:

$$Y = \begin{pmatrix} Y_{SS} & Y_{SL} \\ Y_{LS} & Y_{LL} \end{pmatrix}$$

en het verkrijgen van stroom $[I_S, I_L]^T$ dat door het vermogenstransmissienetwerk vloeit vanuit elk knooppunt, waarbij I_S uitvoerstroom is van een vermogenstoevoerknooppunt en I_L de stroom is die vloeit naar het vermogenstransmissienetwerk van een belastingsknooppunt;
b) het opzetten van een prestatie-index J_1 van lijnverliesoptimalisatie en een prestatie-index J_2 van spanningsaanpassing, en het verkrijgen van een meervoudig doel optimaliseringsprobleem, waarbij

$$J_1 = U_S^T I_S + U_L^T I_L,$$

$$J_2 = \|U_L - U_N\|_2^2,$$

$J = \alpha J_1 + \beta J_2$, wherein $\alpha + \beta = 1$, $\alpha \geq 0$, $\beta \geq 0$,

en waarbij U_S een uitvoerspanning is van een vermogenstoevoerknooppunt U_L de spanning is die naar het vermogenstransmissienetwerk van een laadknooppunt wordt getransporteerd en U_N een geschat belastingsvoltage; en

c) het oplossen van het optimaliseringsprobleem door een gedistribueerd algoritme op basis van een coördinatieafname, waarbij het gedistribueerde algoritme de stappen omvat van:

stap 1: het instellen van een stroomstap $d=d_0$, uitvoerspanning $U_s=U_S^0$, het aantal iteraties $i=0$, en een vermogenstoevoer knooppuntnummer $p=1$, waarbij d_0 een initiële stapgrootte is U_S^0 een initiële voltagewaarde en het aanpassen van een vermogen van het eerste vermogenstoevoer;

stap 2: het verzamelen van belastingsvermogen, vermogensknooppunt vermogen en belastingsvoltage voor feedbackregeling, maar niet meten van een lijn impedantie en het instellen van $i=i+1$;

stap 3: het berekenen van $\alpha J_1+\beta J_2$ dat wordt opgeslagen als $P_{\_ob}(i\text{-}1)$;

stap 4: het toevoegen van een spanningsstap verstoring in een huidig vermogenstoevoerknooppuntvoltage $V_{sp}^{\ i}$, i.e., $V_{sp}^{\ i}=V_{sp}^{\ i-1}+d$, en het ongewijzigd laten van de andere knooppuntvoltages;

stap 5: het opnieuw berekenen van $\alpha J_1+\beta J_2$ dat wordt opgeslagen als $P_{\_ob}(i)$;

stap 6: het vergelijken van $P_{\_ob}(i)$ met $P_{\_ob}(i\text{-}1)$;

stap 7: het wijzigen wanneer $|P_{\_ob}(i)\text{-}P_{\_ob}(i\text{-}1)|<\varepsilon$, van de initiële waarde van de huidige vermogenstoevoer $i=0$, $d=d_0$, $V_{sp}^{\ 0}=V_{sp}^{\ i-1}$, het selecteren van $p+1$, en het gaan naar stap 2;

stap 8: anders het bepalen of $P_{\_ob}(i)\text{-}P_{\_ob}(i\text{-}1)$ waar is, indien ja, het instellen van $d = 1.1d$ en dan het gaan naar stap 2, en indien niet, het uitvoeren van stap 9; en

stap 9: het instellen van $d=-d_0$, en het gaan naar stap 2.

2. De gedistribueerde coöperatieve regelmethode volgens conclusie 1 met het kenmerk dat de prestatie-index J_1 specifiek wordt geïndiceerd als volgt:

$$J_1 = U_S^T (Y_{SS} + Y_{SL} A + A^T Y_{LS} + A^T Y_{LL} A) U_S$$

waarbij $A = -(Y_{LL} + [Y_{Load}])^{-1} Y_{LS}$, en waarbij Y_{Load} de admittantie is van de belasting en Y_{SS}, Y_{SL}, Y_{LS} and Y_{LL} elementen zijn in de admittantiematrix Y, respectievelijk.

3. De gedistribueerde coöperatieve regelmethode volgens conclusie 2, met het kenmerk dat de prestatie-index J_2 specifiek wordt geïndiceerd als volgt: $J_2 = U_S^T A^T A U_S - 2U_N^T A U_S + U_N^T U_N$

4. De gedistribueerde coöperatieve regelmethode volgens conclusie 1, met het kenmerk dat de vermogenstoevoer knooppunten zijn verdeeld als masterknooppunten en slaafknooppunten, waarbij elk masterknooppunt informatie verzamelt van aanliggende belastingen en deze overbrengt naar de slaafknooppunten,

$$\begin{cases} \dot{V}_{Li}^{(i)} = \sum_{l=1}^{k} a_{ij}(V_{Ll}^{(l)} - V_{Li}^{(i)}), & \forall i \in N - \Omega \\ \dot{P}_{Li}^{(i)} = \sum_{l=1}^{k} a_{ij}(P_{Ll}^{(l)} - P_{Li}^{(i)}), & \forall i \in N - \Omega \\ \dot{P}_{si}^{(i)} = \sum_{l=1}^{k} a_{ij}(P_{sl}^{(l)} - P_{si}^{(i)}), & \forall i \in N - \Omega \end{cases}$$

waarbij Ω een collectie is van master knooppunten,

N een totaal aantal is van vermogenstoevoerknooppunten,

V_{Li}, P_{Li}, en P_{si}. belastingsknooppuntvoltage informatie zijn, respectievelijk belastingsknooppuntvermogensinformatie, en vermogenstoevoerknooppunt vermogensinformatie die worden ontvangen van een knooppunt, waarbij

V_{Ll}, P_{Ll}, en P_{sl} respectievelijk belastingsknooppuntvoltage informatie, belastingsknooppunt vermogensinformatie en vermogenstoevoerknooppunt vermogensinformatie van een naburig knooppunt zijn

en a_{ij} een gewichtscoëfficient is van een communicatienetwerk waarbij a_{ij}=1 wanneer een i^{th} vermogenstoevoer in datacommunicatie is met een j^{th} vermogenstoevoer, en anders a_{ij}=0.

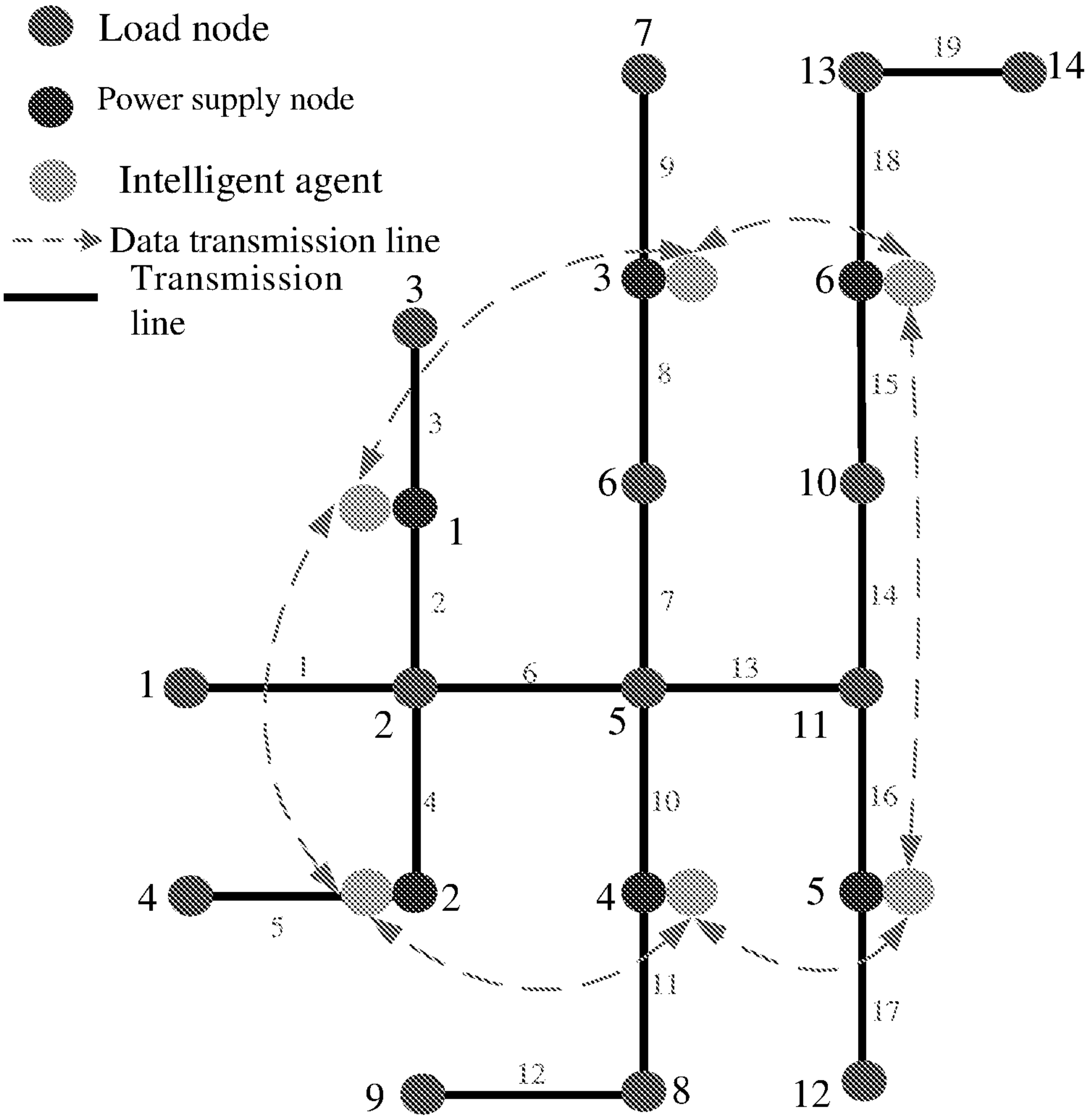
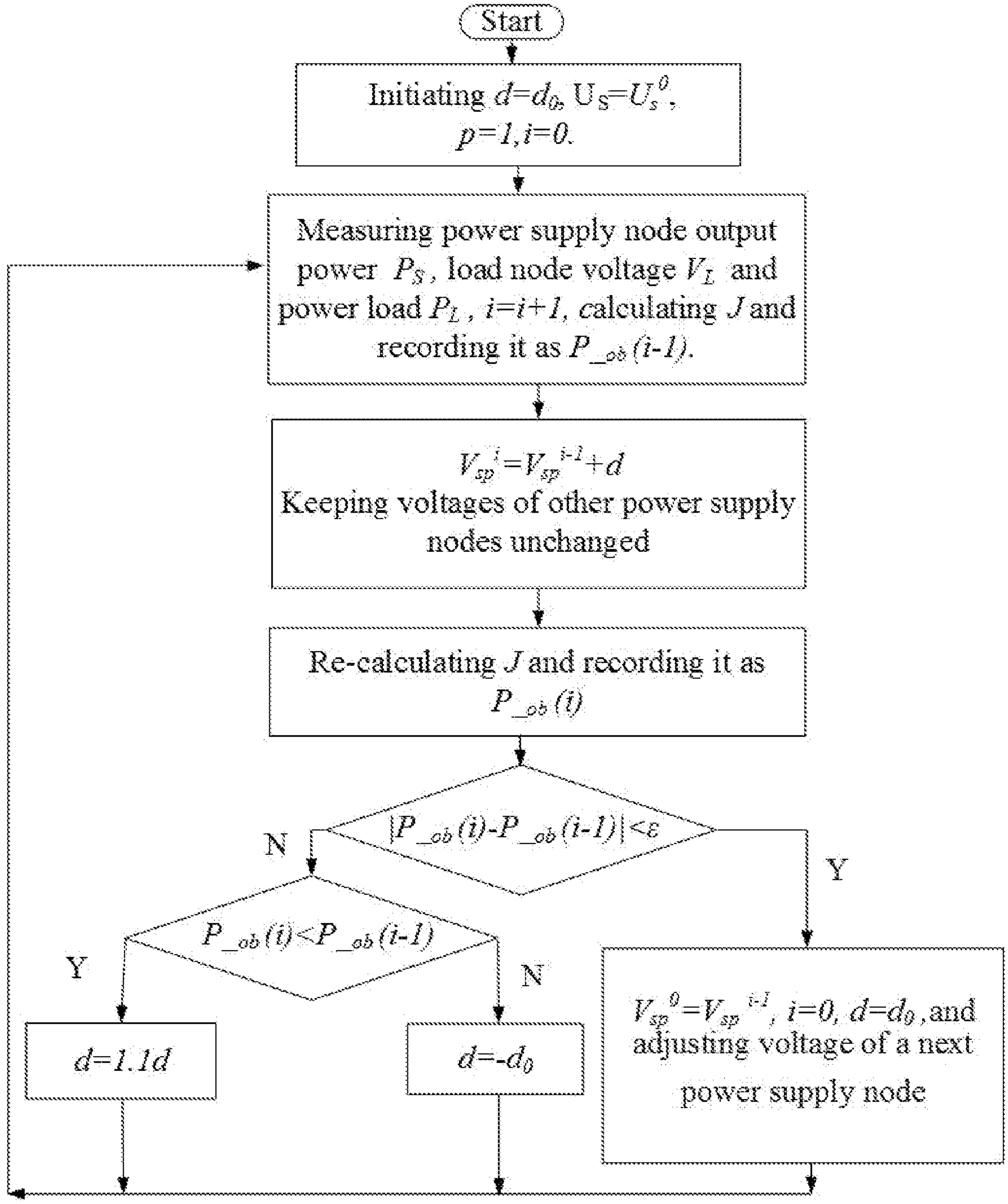
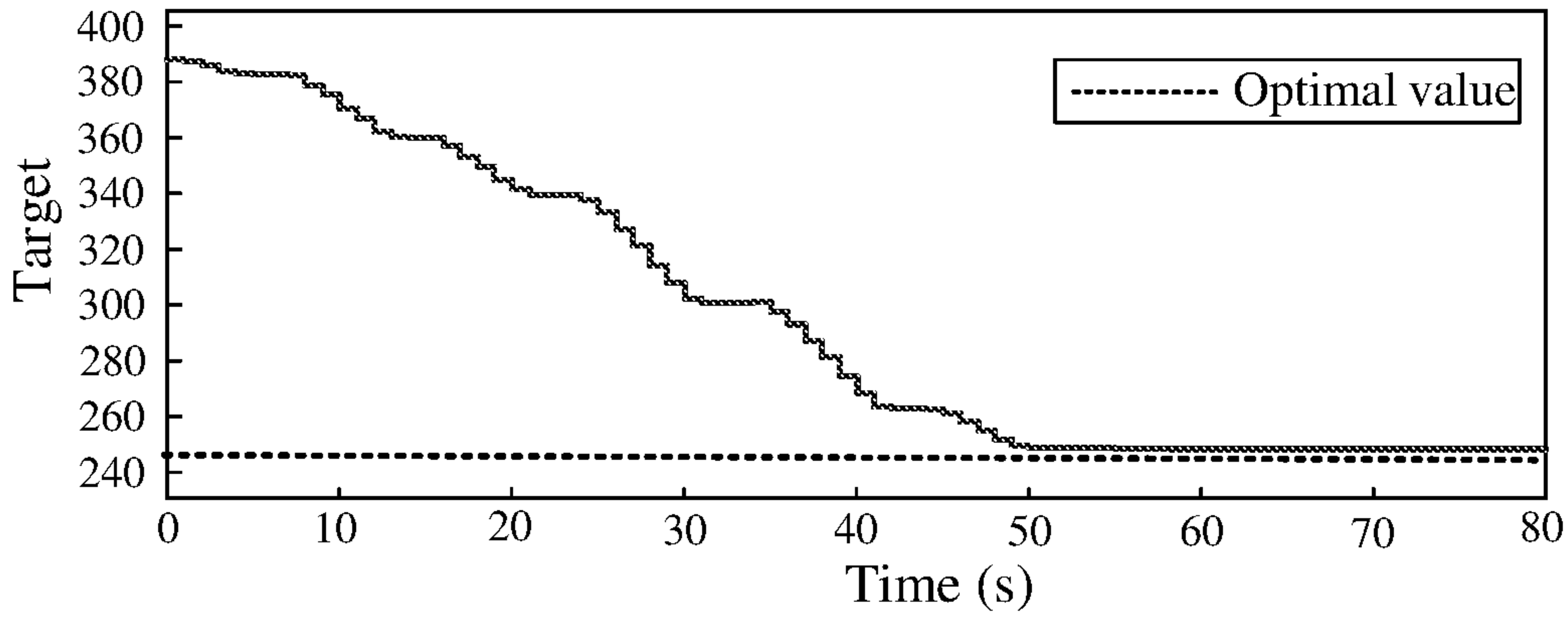

Load node
Power supply node
Intelligent agent
Data transmission line
Transmission line
7
13
19
14
9
18
3
3
6
8
15
3
1
6
10
2
7
14
1
1
6
13
2
5
11
4
10
16
4
5
4
2
4
5
11
17
12
9
12
8
12

Fig. 1

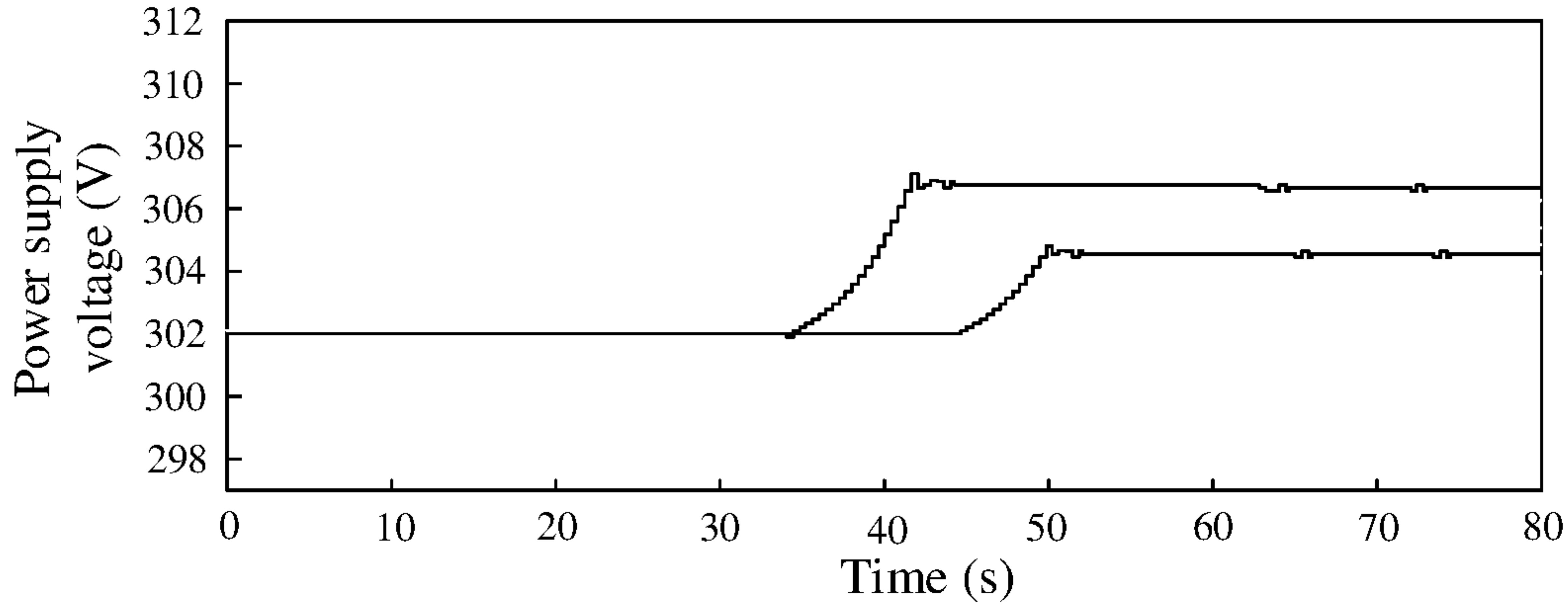


Start
Initiating d=d0, US=Us0, p=1, i=0.
Measuring power supply node output power PS, load node voltage VL and power load PL, i=i+1, calculating J and recording it as P_ob(i-1).
Vspi=Vspi-1+d
Keeping voltages of other power supply nodes unchanged
Re-calculating J and recording it as P_ob(i)
|P_ob(i)-P_ob(i-1)|<ε
N
Y
P_ob(i)<P_ob(i-1)
Y
N
d=1.1d
d=-d0
Vsp0=Vspi-1, i=0, d=d0, and adjusting voltage of a next power supply node

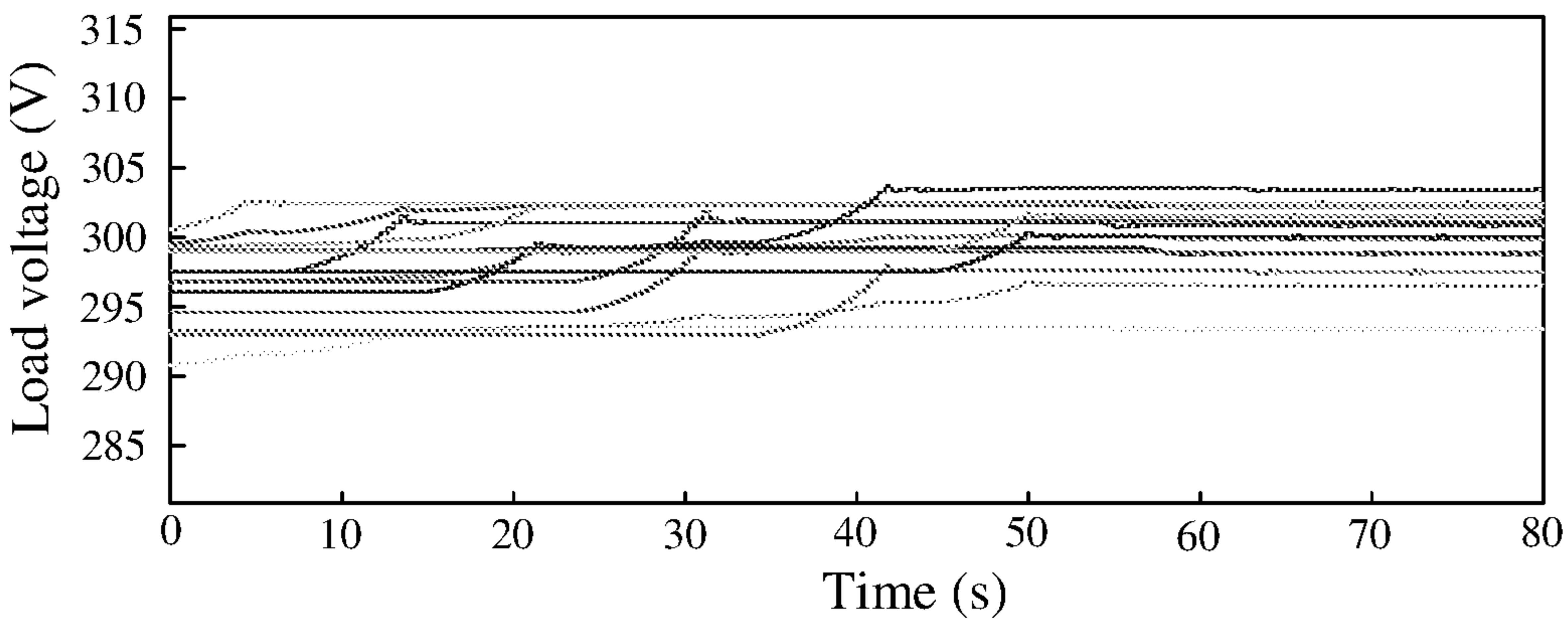
Fig. 2


Optimal value
Target
Time (s)
400
380
360
340
320
300
280
260
240
0
10
20
30
40
50
60
70
80

a-1

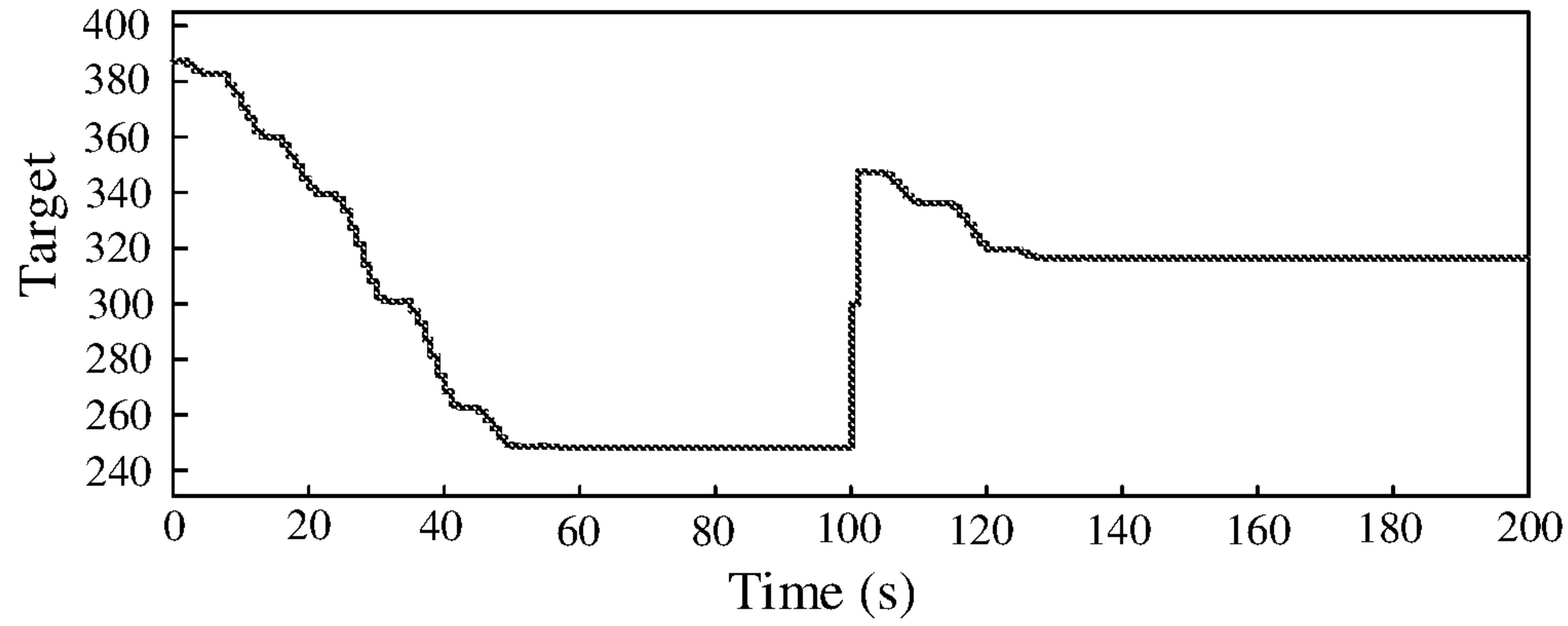

Power supply voltage (V)
Time (s)
312
310
308
306
304
302
300
298
0
10
20
30
40
50
60
70
80

a-2

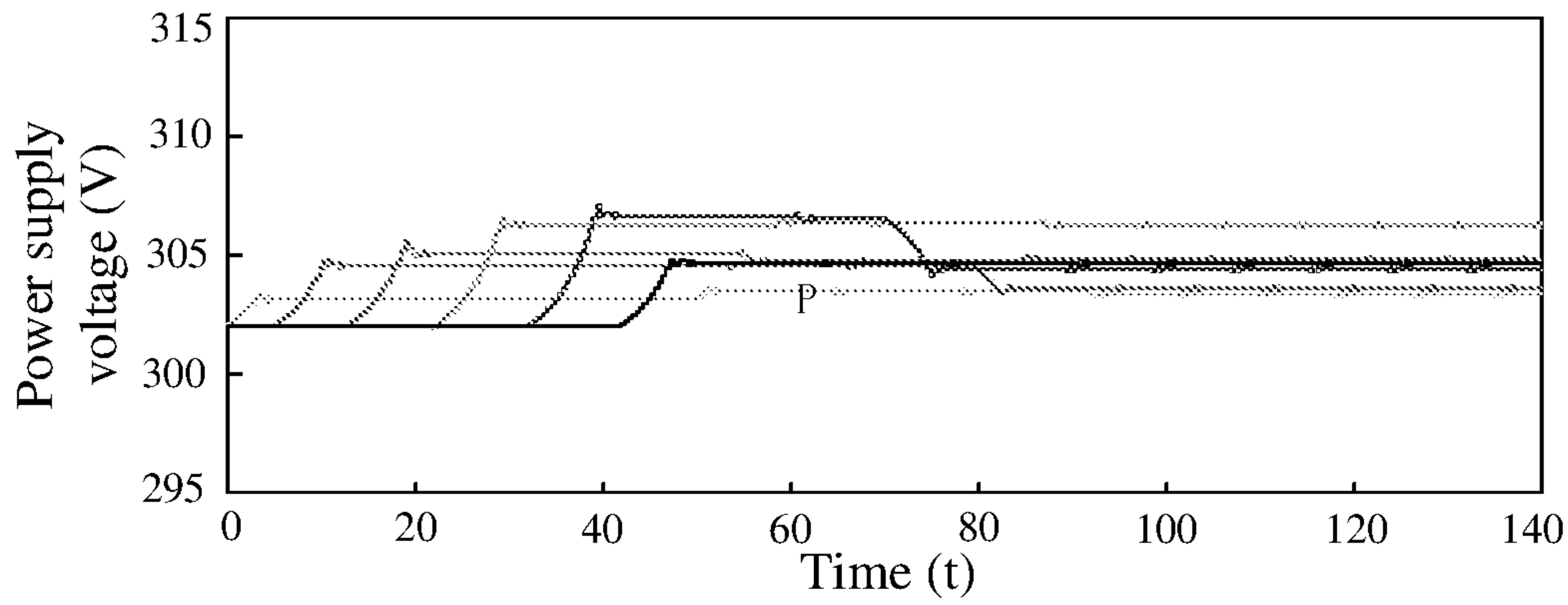

Load voltage (V)
Time (s)
315
310
305
300
295
290
285
0
10
20
30
40
50
60
70
80

a-3

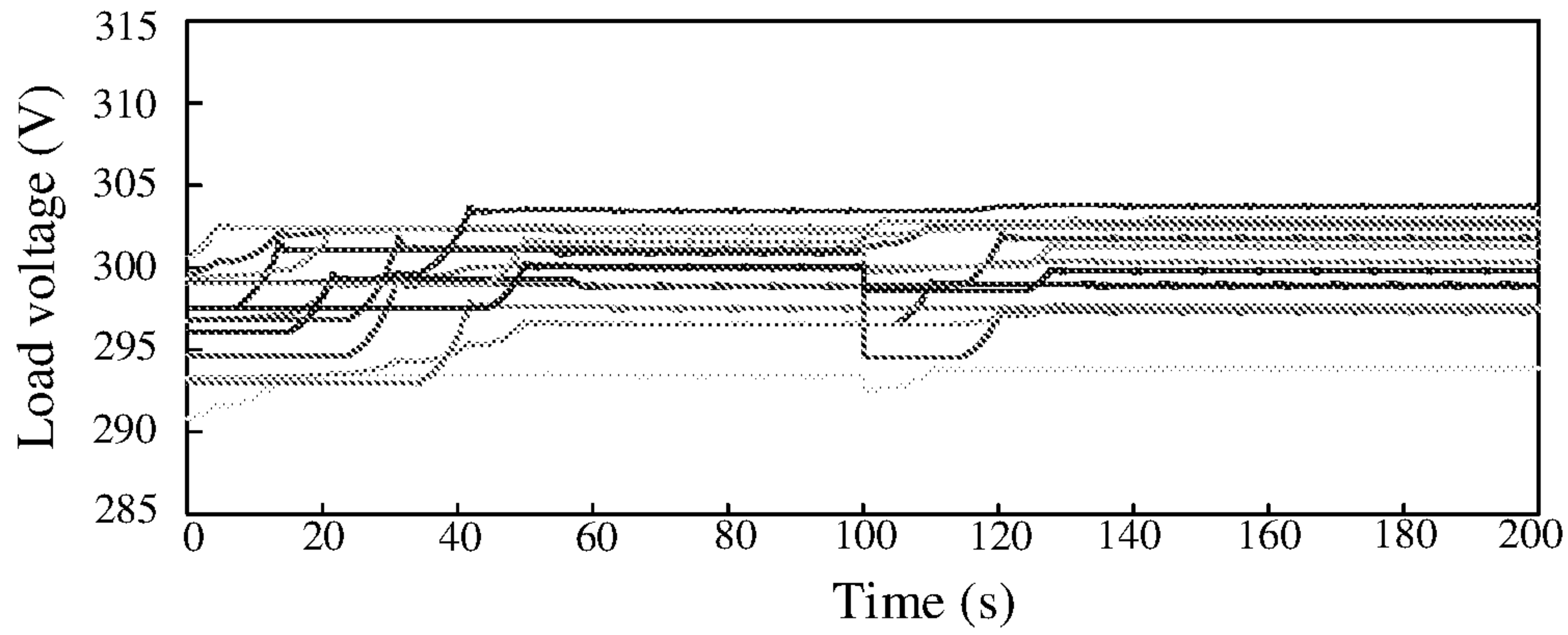
Fig. 3


Target
400
380
360
340
320
300
280
260
240
0
20
40
60
80
100
120
140
160
180
200
Time (s)

b-1

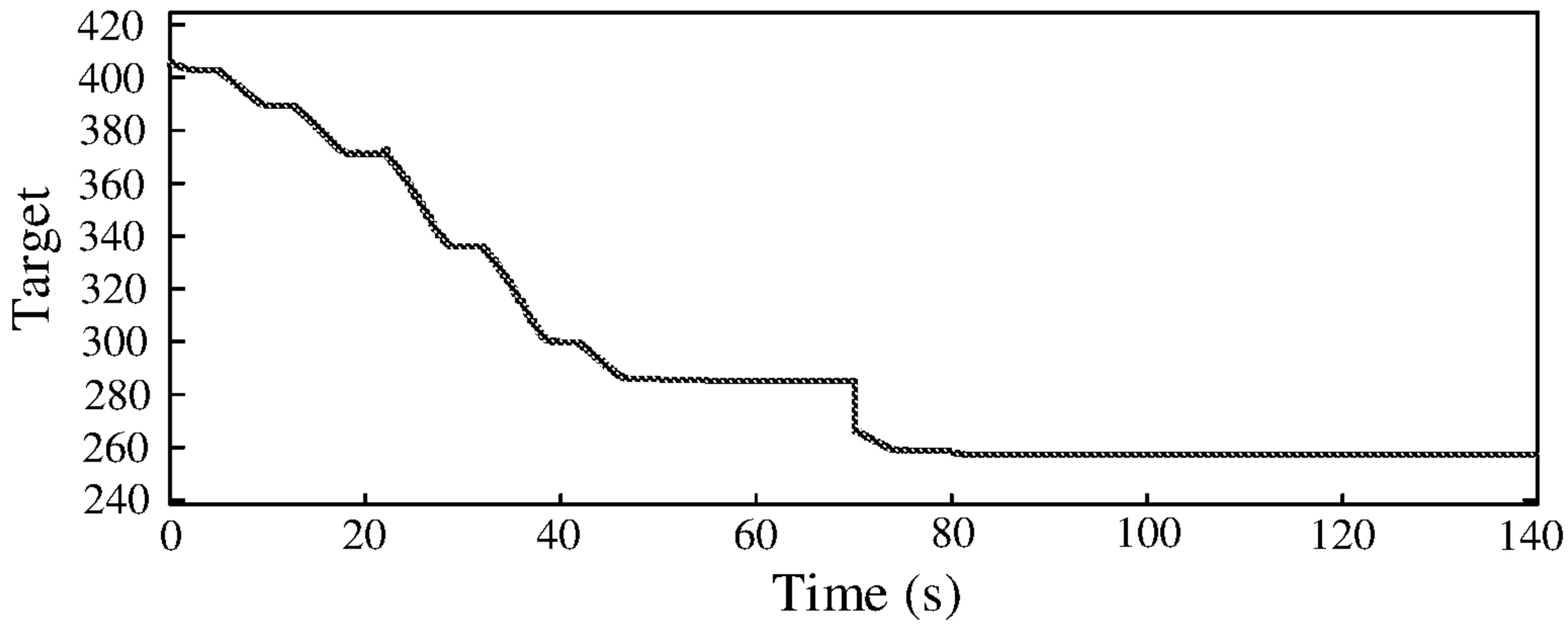

Power supply voltage (V)
315
310
305
300
295
P
0
20
40
60
80
100
120
140
Time (t)

b-2

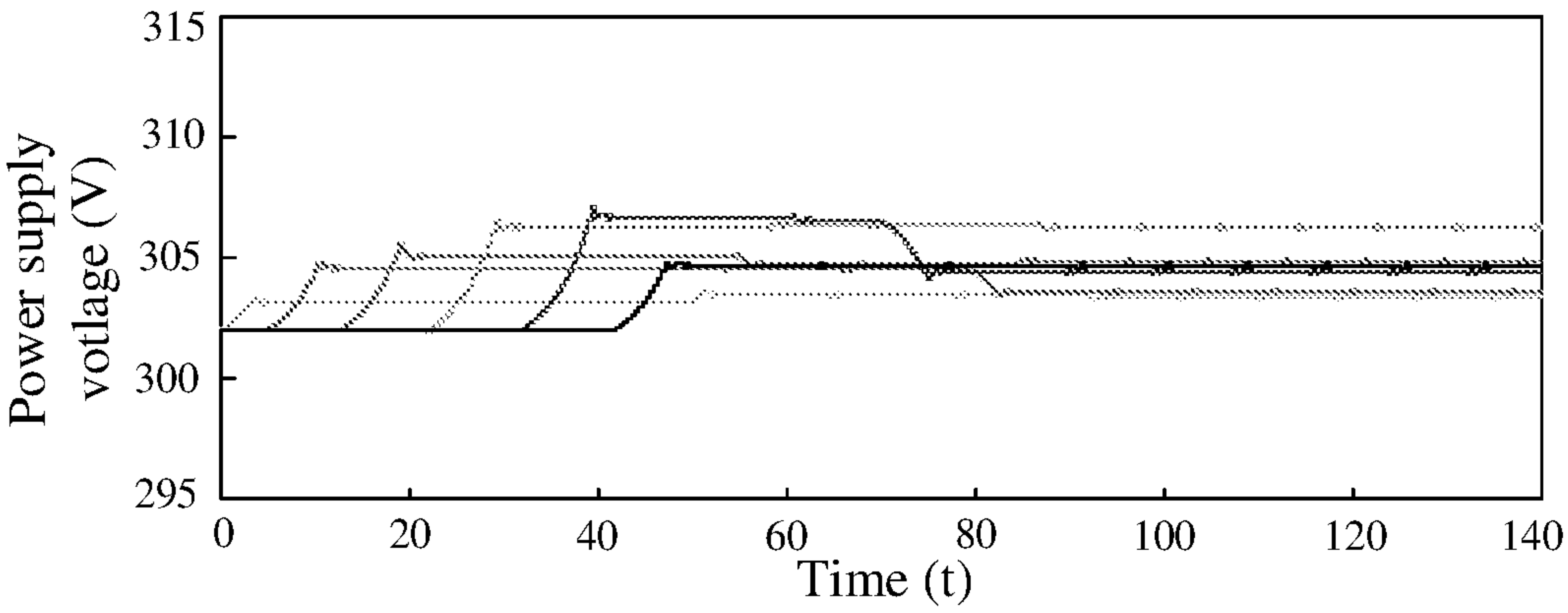

Load voltage (V)
315
310
305
300
295
290
285
0
20
40
60
80
100
120
140
160
180
200
Time (s)

b-3

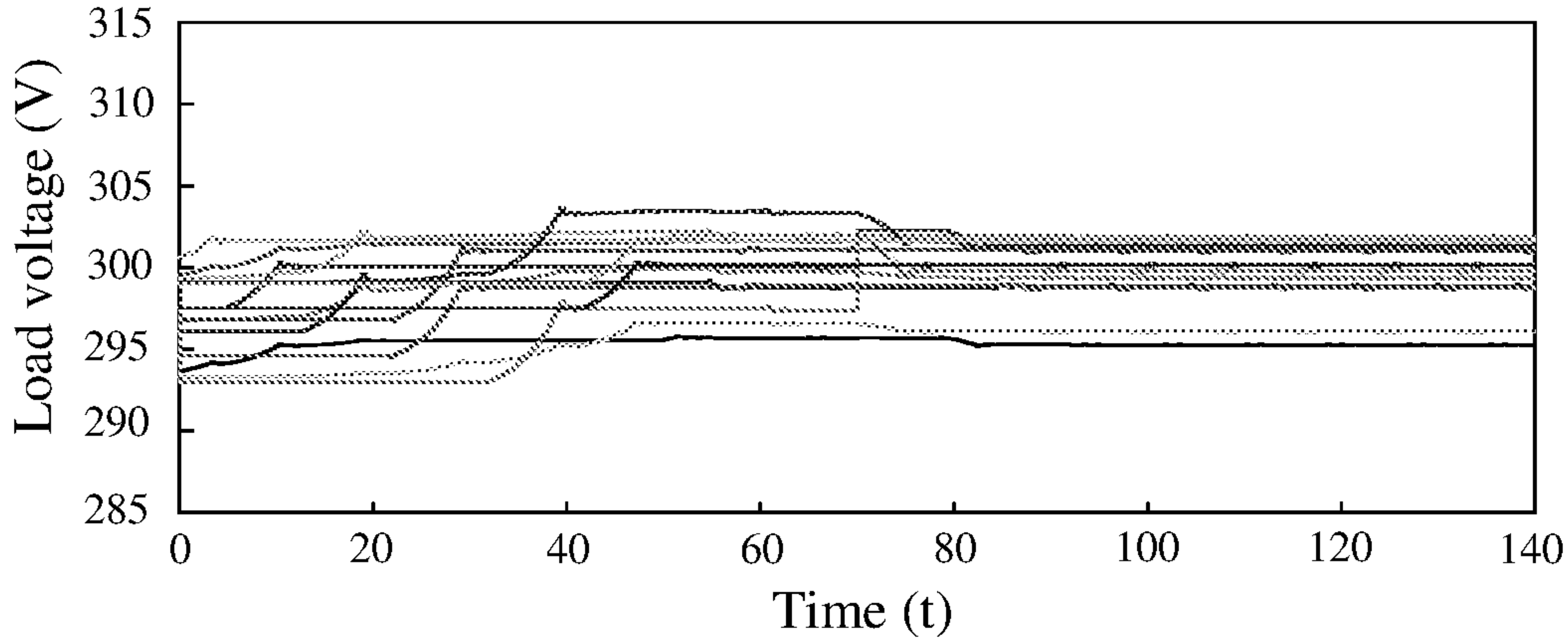
Fig. 4


420
400
380
360
340
320
300
280
260
240
Target
0
20
40
60
80
100
120
140
Time (s)

c-1

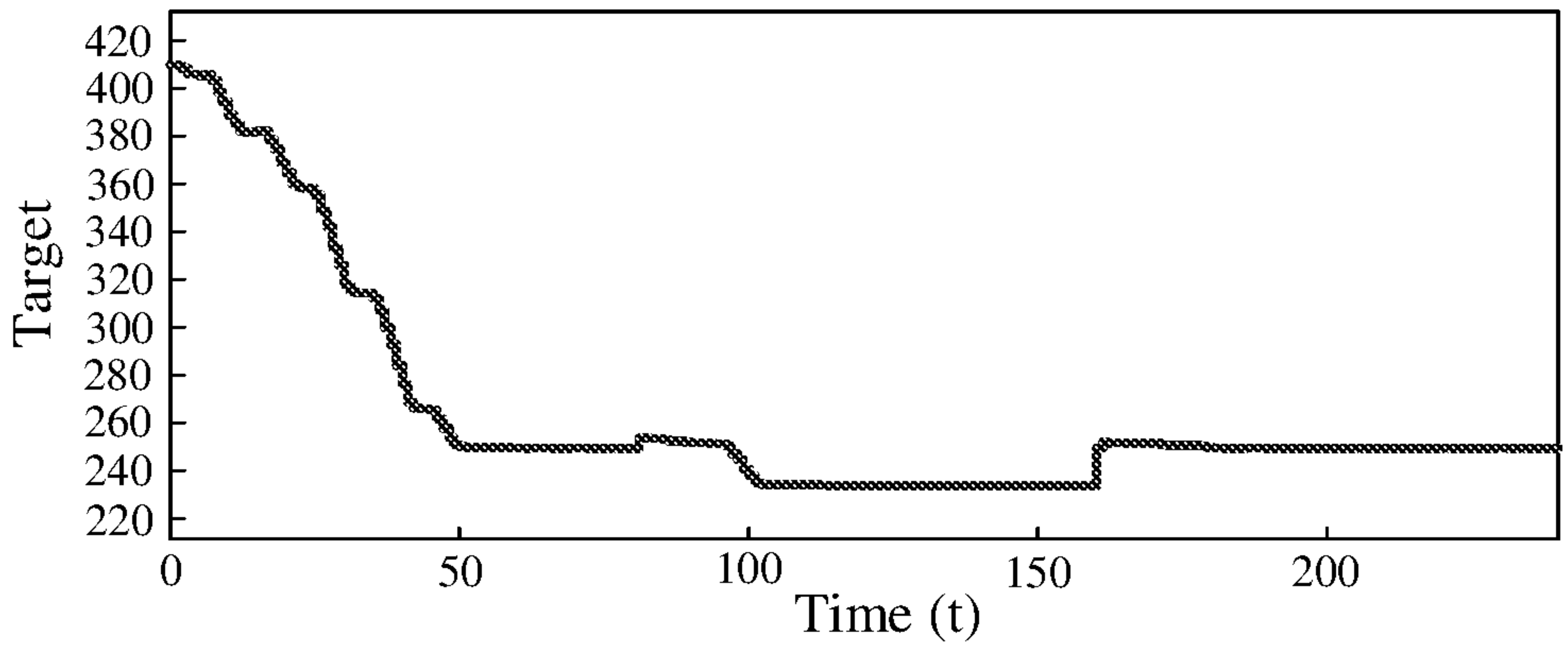

315
310
305
300
295
Power supply votlage (V)
0
20
40
60
80
100
120
140
Time (t)

c-2

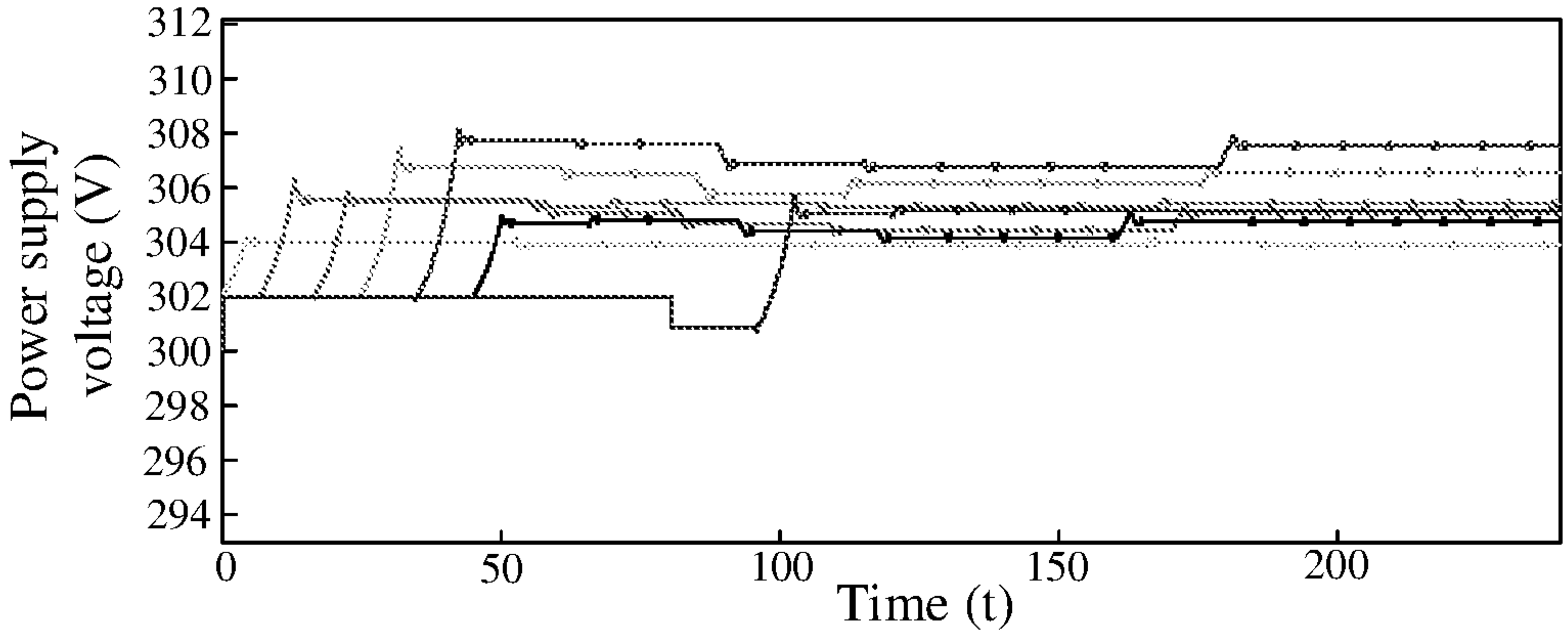

315
310
305
300
295
290
285
Load voltage (V)
0
20
40
60
80
100
120
140
Time (t)

c-3

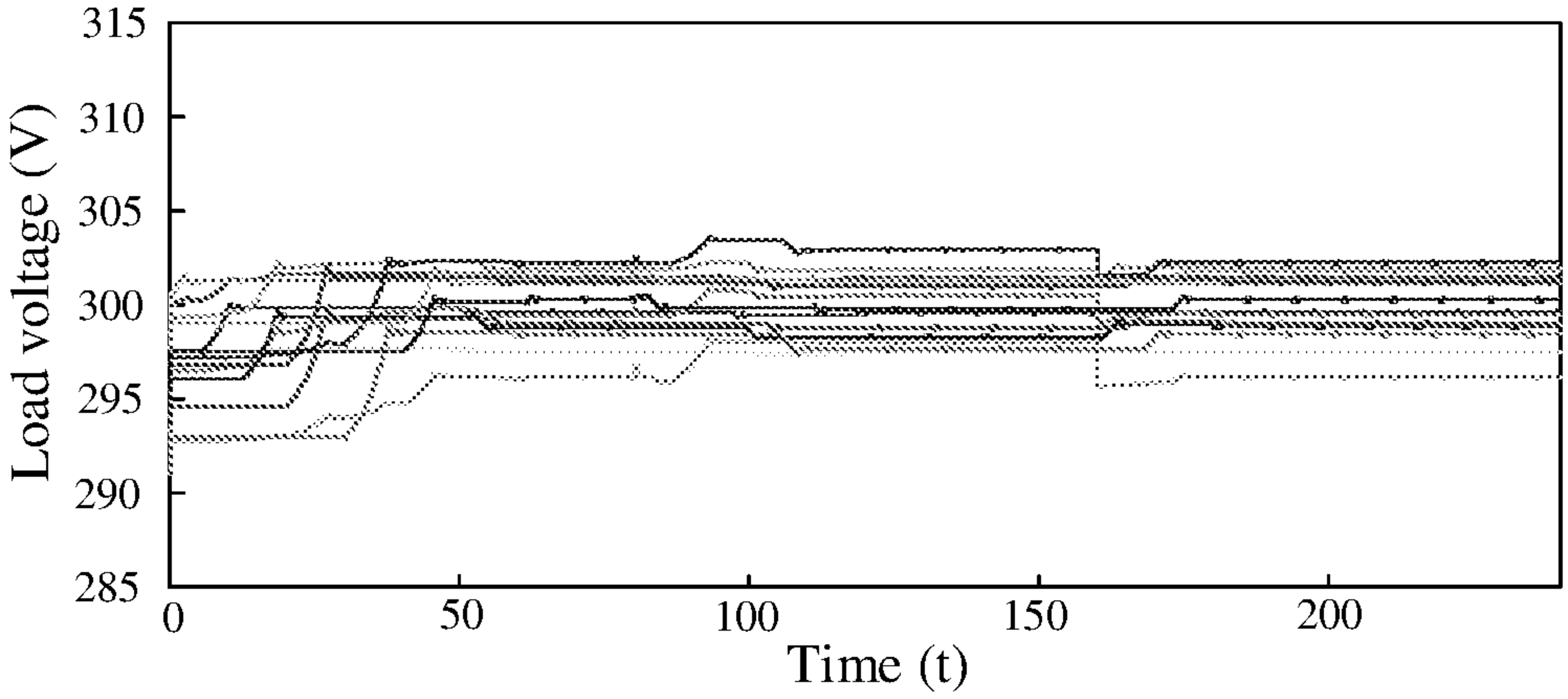
Fig. 5


Target
420
400
380
360
340
320
300
280
260
240
220
0
50
100
150
200
Time (t)

d-1


Power supply voltage (V)
312
310
308
306
304
302
300
298
296
294
0
50
100
150
200
Time (t)

d-2


Load voltage (V)
315
310
305
300
295
290
285
0
50
100
150
200
Time (t)

d-3

Fig. 6

Rijksdienst voor Ondernemend Nederland

OCTROOIAANVRAAG NR.:
NO 140646
NL 2024943

ONDERZOEKSRAPPORT

BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK

RELEVANTE LITERATUUR

Categorie[1]	Literatuur met, voor zover nodig, aanduiding van speciaal van belang zijnde tekstgedeelten of figuren.	Van belang voor conclusie(s) nr:	Classificatie (IPC)
A	CN 109 617 079 A (UNIV SOUTH CHINA TECH ET AL.) 12 april 2019 (2019-04-12)	1-4	INV. H02J1/10 G06F30/00 G06F30/20 G05B13/04
A	US 10 126 802 B1 (UNIV CHONGQING [CN]) 13 november 2018 (2018-11-13)	1-4	
A	CHEW BENJAMIN SI HAO ET AL: "Voltage Balancing for Bipolar DC Distribution Grids: A Power Flow Based Binary Integer Multi-Objective Optimization Approach", IEEE TRANSACTIONS ON POWER SYSTEMS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, deel 34, nr. 1, 1 januari 2019 (2019-01-01), bladzijden 28-39, XP011701180, ISSN: 0885-8950, DOI: 10.1109/TPWRS.2018.2866817 [gevonden op 2018-12-19]	1-4	
A	SHENG WANXING ET AL: "Optimal power flow algorithm and analysis in distribution system considering distributed generation", IET GENERATION, TRANSMISSION&DISTRIBUTION, IET, UK, deel 8, nr. 2, 1 februari 2014 (2014-02-01), bladzijden 261-272, XP006047128, ISSN: 1751-8687, DOI: 10.1049/IET-GTD.2013.0389	1-4	**Onderzochte gebieden van de techniek:** H02J G06F

Indien gewijzigde conclusies zijn ingediend, heeft dit rapport betrekking op de conclusies ingediend op:

Plaats van onderzoek:	Datum waarop het onderzoek werd voltooid:	Bevoegd ambtenaar:
München	14 juli 2020	Jansen, Helma

[1] CATEGORIE VAN DE VERMELDE LITERATUUR

X: de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur
Y: de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht
A: niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft
O: niet-schriftelijke stand van de techniek
P: tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur
T: na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvrage, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding
E: eerdere octrooi(aanvrage), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven
D: in de octrooiaanvrage vermeld
L: om andere redenen vermelde literatuur
&: lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

AANHANGSEL BEHORENDE BIJ HET RAPPORT BETREFFENDE HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK, UITGEVOERD IN DE OCTROOIAANVRAGE NR.

NO 140646
NL 2024943

Het aanhangsel bevat een opgave van elders gepubliceerde octrooiaanvragen of octrooien (zogenaamde leden van dezelfde octrooifamilie), die overeenkomen met octrooischriften genoemd in het rapport.
De opgave is samengesteld aan de hand van gegevens uit het computerbestand van het Europees Octrooibureau per
De juistheid en volledigheid van deze opgave wordt noch door het Europees Octrooibureau, noch door het Bureau voor de Industriële eigendom gegarandeerd; de gegevens worden verstrekt voor informatiedoeleinden.

14-07-2020

In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
CN 109617079 A	12-04-2019	GEEN	
US 10126802 B1	13-11-2018	CN 107342586 A	10-11-2017
		US 10126802 B1	13-11-2018

SCHRIFTELIJKE OPINIE

DOSSIER NUMMER	INDIENINGSDATUM	VOORRANGSDATUM	AANVRAAGNUMMER
NO140646	19.02.2020	30.04.2019	NL2024943
CLASSIFICATIE INV. H02J1/10 G06F30/00 G06F30/20 G05B13/04			
AANVRAGER Central South University			

Deze schriftelijke opinie bevat een toelichting op de volgende onderdelen:

- ☒ Onderdeel I Basis van de schriftelijke opinie
- ☐ Onderdeel II Voorrang
- ☐ Onderdeel III Vaststelling nieuwheid, inventiviteit en industriële toepasbaarheid niet mogelijk
- ☐ Onderdeel IV De aanvraag heeft betrekking op meer dan één uitvinding
- ☒ Onderdeel V Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid
- ☐ Onderdeel VI Andere geciteerde documenten
- ☐ Onderdeel VII Overige gebreken
- ☐ Onderdeel VIII Overige opmerkingen

	DE BEVOEGDE AMBTENAAR
	Jansen, Helma

Aanvraag nr.:

SCHRIFTELIJKE OPINIE

NL2024943

Onderdeel I Basis van de Schriftelijke Opinie

1. Deze schriftelijke opinie is opgesteld op basis van de meest recente conclusies ingediend voor aanvang van het onderzoek.

2. Met betrekking tot **nucleotide en/of aminozuur sequenties** die genoemd worden in de aanvraag en relevant zijn voor de uitvinding zoals beschreven in de conclusies, is dit onderzoek gedaan op basis van:

   a. type materiaal:

   ☐ sequentie opsomming

   ☐ tabel met betrekking tot de sequentie lijst

   b. vorm van het materiaal:

   ☐ op papier

   ☐ in elektronische vorm

   c. moment van indiening/aanlevering:

   ☐ opgenomen in de aanvraag zoals ingediend

   ☐ samen met de aanvraag elektronisch ingediend

   ☐ later aangeleverd voor het onderzoek

3. ☐ In geval er meer dan één versie of kopie van een sequentie opsomming of tabel met betrekking op een sequentie is ingediend of aangeleverd, zijn de benodigde verklaringen ingediend dat de informatie in de latere of additionele kopieën identiek is aan de aanvraag zoals ingediend of niet meer informatie bevatten dan de aanvraag zoals oorspronkelijk werd ingediend.

4. Overige opmerkingen:

Aanvraag nr.:

SCHRIFTELIJKE OPINIE

NL2024943

Onderdeel V Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid

1. Verklaring

Nieuwheid	Ja:	Conclusies 1-4
	Nee:	Conclusies
Inventiviteit	Ja:	Conclusies 1-4
	Nee:	Conclusies
Industriële toepasbaarheid	Ja:	Conclusies 1-4
	Nee:	Conclusies

2. Citaties en toelichting:

Zie aparte bladzijde

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1 Reference is made to the following document:

D1 CN 109 617 079 A (UNIV SOUTH CHINA TECH ET AL.) 12 april 2019 (2019-04-12)

2 Document D1 (CN109617079, for better understanding, it is referred to the enclosed machine translation) is regarded as being the prior art closest to the subject-matter of claim 1, and discloses:

2.1 A method for analyzing the power flow of a DC power grid including
a) enabling a topology of a mesh-like DC power system, which contains n power supply nodes and m load nodes, to be equivalent to a graph based on graph theory, to obtain a corresponding admittance matrix Y of a power transmission network Y and obtain, according Ohm's Law, current $[Is, IL]^T$ flowing to the power transmission network from each node, wherein Is is output current from a power supply node, and IL is current flowing to the power transmission network from a load node.

2.2 The subject-matter of claim 1 therefore differs from this known power flow analyzing method in that:
b) setting a performance index Ji on line loss optimization and a performance index J2 on voltage adjustment, and establishing a multiple-objective optimal problem,
c) solving said optimal problem through an improved distributed algorithm based on coordination descent, wherein the distributed algorithm includes steps of:
step 1: setting current step size d=do, output voltage $U_s=U_s^0$, number of iterations i=0, and power supply node number p=1, wherein d_o is an initial step size, U_s^0 is an initial voltage value, and adjusting a power of a first power supply;
step 2: collecting load power, power node power, and load voltage for feedback control, setting i=i+1;
step 3: calculating $aJ,+ \beta J_2$, which is recorded as $P_{\_ob}$ (i-1);
step 4: adding a voltage step disturbance into a current power supply node voltage V_{sp}^{i}, i.e., $V_{sp} = V_{sp}^{i-1}$ +d, and keeping other node voltages unchanged;
step 5: recalculating $aJ,+ \beta J_2$, which is recorded as $P_{\_ob}$ (i);
step 6: comparing P_b (i) with $P_{\_ob}$ (i -1);

step 7: changing, when $IP_{\_b}(i) - P_{\_ob}(i-1)|<\varepsilon$, the initial value of the current power supply i=0, $d=d_o$, $V_{sp}^0 = V_{sp}^{i-1}$, selecting p+1, and going to step 2;
stap 8: otherwise, determining whether $P_{\_ob}(i) - P_{\_ob}(i-1)$ is true, if yes, setting d = 1.1d and then going to step 2, if not performing step 9; and
stap 9: setting d=-do, and going to step 2.

2.3 and is therefore new.

2.4 The problem to be solved by the present invention may be regarded as providing an improved power flow analyzing method.

2.5 The solution to this problem proposed in claim 1 of the present application is considered as involving an inventive step for the following reasons:
The method of claim 1 proposed a different approach to analyze the power flow. This method is not disclosed or hinted at in any of the documents cited in the search report.

3 Claims 2-4 are dependent on one the independent claim whose subject-matter is considered as being new and inventive, as discussed above, and as such said dependent claims also meet the requirements of novelty and inventive step.