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Intentional Islanding Operations of Distributed Generation Systems with a Load Shedding Algorithm

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Abstract—*Intentional islanding is a condition in which a distributed generation source continues to supply power to the local loads during a catastrophic utility failure. With a properly co-ordinated and sophisticated control scheme, islanding can be a possible solution, to ensure reliable power to the critical loads. This paper analyzes a control scheme for intentional islanding operation of an inverter based DG system. In grid connected mode, the interface control is designed to provide constant active and reactive power to the load. When grid is disconnected, an islanding detection algorithm will transfer the inverter into voltage control mode. The mismatch between load and generation is removed by implementing a load shedding algorithm. This paper also investigates the performance and the Non Detection Zones of the islanding detection scheme with different interface controllers.*

Key words—Distributed generation (DG), Grid connected mode, Islanded mode, Anti islanding methods, Non Detection Zone (NDZ), Point of Common Coupling (PCC)

I. INTRODUCTION

The gap between the generation and demand of the power provided by conventional sources of power is fast increasing. This is due to inadequate transmission capacity and the non uniform allocation of load and generating centers. The need of the hour is to tap the potential of distributed generation to meet the increasing power demand. However, many problems arise due to the change in power grid paradigm from the conventional centralized power stations to the deregulated structure [1]. One of the major concerns in this regard is islanding. Islanding is a condition in which a part of distribution network is supplied by a DG, even when the main grid is disconnected from the system [2]. The island will remain operational for a long time, if the DG alone can meet the local load demand. This may interfere with the recloser system, protection co-ordination and can even lead to hazards. In spite of the fact that the likelihood of the islanding is very less, because of the above mentioned problems, current standards require disconnection of the DG system from the grid when islanding is detected [3]. Also controlled islanding can improve the reliability of the power system considerably. Moreover in a system with high DG penetration, the disconnection can create several power quality problems. Hence in order to maximize the benefits from DG, it is advisable to go for intentional islanding. IEEE 1547 states that one of its tasks for future consideration is the implementation of intentional islanding [4].

To implement a successful intentional island, the system should detect the islanding event, as soon as the grid gets disconnected. An efficient islanding detection algorithm is needed for this task. Several islanding detection methods are proposed in the literature. These can be broadly classified as local methods and remote methods. Remote methods are based on the communication between local DG and the utility grid whereas local methods rely on monitoring parameters like voltage and frequency at the DG site [5]-[6].

Many works have been reported in the literature regarding the interface and control of the DG systems in grid connected and islanding modes. In [7], two control algorithms are proposed for grid connected and islanded operation, with an intelligent load shedding algorithm and an algorithm for synchronization. In [8], the effect of different interface control on islanding detection is analyzed. Reference [9] proposes a control strategy based on voltage controlled voltage source converter which inherently provide an islanding detection method with negligible NDZ.

This paper presents a control strategy for grid connected as well as islanding modes of operation. Initially the DG system operates in a current controlled mode to provide the required power to the load. When the grid gets disconnected, a simple passive detection algorithm transfers the system to voltage control mode. A priority based load shedding scheme, based on the measurement of the voltage at PCC, is used to neutralize the load generation mismatch.

The paper is organized as follows. Section II introduces a study system and systematically explains the modeling of the control scheme for grid connected and islanding modes. Section III explains the islanding detection algorithm and the analytical explanation for the NDZ. Section IV presents the load shedding algorithm. Section V analyzes the performance of the system by conducting time domain simulations in MATLAB/SIMULINK. Section VI concludes the paper.

II. STUDY SYSTEM

Fig.1 shows the single line diagram of the system under study. The system consists of a DG represented by a dc source interfaced to the grid through a voltage source inverter, LC filter and a breaker. L and C represent the inductance and capacitance values of the filter and R represents the combined ohmic losses in the filter inductor and on state resistance of the

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VSI. Two parallel RLC loads are connected to the system. The interface control is designed with PI controllers, with the control variables defined in the synchronous reference frame. A phase locked loop (PLL) is used to determine the frequency and angular reference at the Point of Common Coupling (PCC).

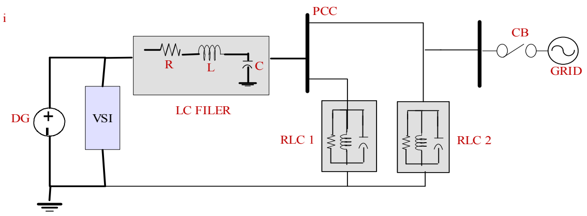


Figure.1.Single line diagram of the system under study

A. Modeling of the System in DQ Frame

From the single line diagram,

$$V_{ik}(t)=V_{gk}(t)+R_i i_k(t)+L_i\frac{di_k(t)}{dt} \qquad (1)$$

R_i, L_i are the resistance and inductance between DG and PCC which includes the resistance and inductance of the filter also. V_{ik}, V_{gk} represents the inverter side voltage and grid side voltage respectively and k=a, b, c.

Applying park transformation, (1) becomes,

$$V_{id}(t)=V_{gd}(t)+R_i i_d(t)+L_i\frac{di_d(t)}{dt}-\omega L_i i_q(t) \qquad (2)$$

$$V_{iq}(t)=V_{gq}(t)+R_i i_q(t)+L_i\frac{di_q(t)}{dt}+\omega L_i i_d(t) \qquad (3)$$

Where 'ω' is the angular frequency of the system.

B. Grid Connected Mode

In grid connected mode, DG should provide constant active and reactive power to the system. The voltage and frequency at the point of common coupling are dictated by the grid. The synchronization process is carried out by the 3 phase PLL, which sets V_{gq} as zero. Hence according to instantaneous power theory, real and reactive power can be represented in dq frame as

$$P=\frac{3}{2}V_{gd}i_d \qquad (4) \qquad\qquad Q=-\frac{3}{2}V_{gd}i_q \qquad (5)$$

Where V_{gd} is the maximum value of the voltage at the point of common coupling and i_d and i_q are the components of the current in the dq axis. According to (4) and (5), active and reactive power components can be decoupled and controlled separately, by controlling i_d and i_q values.

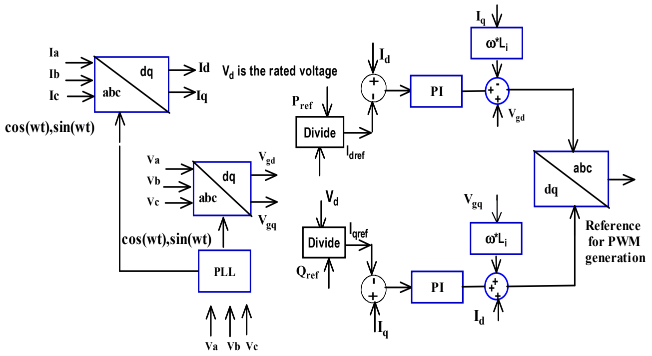


Figure.2.Block diagram of current controlled mode of operation

Equation (2) and (3) can be rewritten as

$$V_{id}'(s)=V_{id}(s)-V_{gd}(s)-\omega L_i i_q(s) \qquad (6)$$

$$V_{iq}'(s)=V_{iq}(s)-V_{gq}(s)+\omega L_i i_d(s) \qquad (7)$$

$V_{id}'(s)$ and $V_{iq}'(s)$ can be defined as:

$$V_{id}'(s)=R_i i_d(s)+sL_i i_d(s) \qquad (8)$$

$$V_{iq}'(s)=R_i i_q(s)+sL_i i_q(s) \qquad (9)$$

The transfer function of the system to be controlled is

$$\frac{V_{id}'(s)}{i_d(s)}=\frac{V_{iq}'(s)}{i_q(s)}=G(s)=\frac{1}{R_i+sL_i} \qquad (10)$$

The error between the reference current and the inverter output current is processed by PI controllers. As the control is implemented in the synchronous frame, the inputs to the PI controllers are dc quantities. The controller reduces the steady state error to zero and generate modulating reference for the PWM switching.

C. Islanded Mode

In autonomous or islanded mode, the above mentioned conventional current controlled strategy is not suitable, as there is no grid to maintain the voltage and frequency at the PCC. Hence when grid is disconnected, the interface controller should be switched to a voltage control mode. Normally, instead of directly controlling voltage, voltage control through current compensation, is suggested in the literature. This scheme allows current limiting and enhances system protection.

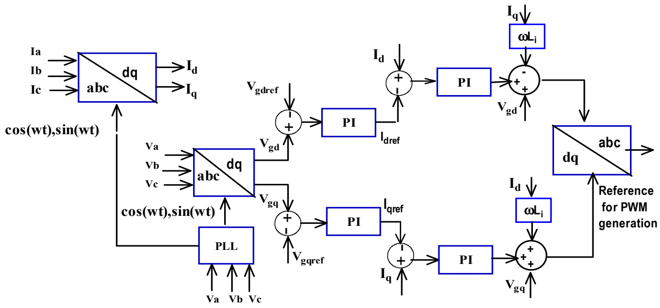


Figure.3.Block diagram for islanded mode of operation

III. ISLANDING DETECTION ALGORITHM

In our system we consider a simple hybrid passive islanding detection method based on frequency (OFP/UFP) and voltage (OVP/UVP) measurement, for implementing the intentional islanding operations. The frequency and voltage variations are dependent on the load generation mismatch. If these parameters exceed the threshold specified by the algorithm, islanding will be detected.

An islanding detection algorithm should be dependable, secure and fast. It should discriminate between islanding and other events and should detect all possible formation of islands. The threshold value is decided based on the above requirements. Moreover, with this algorithm, islanding is detected only if the parameter excursions remain for a sufficient time delay. This will help to prevent the misinterpretation of other grid dynamics for islanding. Islanding detection algorithm is shown in Fig.4.

But if the generation-load mismatch is negligible, this algorithm cannot detect islanding within the required time frame and will produce Non Detection Zones. NDZ is defined as the range of loads for which islanding is not detected. For a constant power controlled interface operating in unity power factor mode, the NDZ for OVP/UVP and OFP/UFP can be derived as (11) and (12)

$$\left[V/V_{\max}\right]^2 - 1 \le \frac{\Delta P}{P} \le \left[V/V_{\min}\right]^2 - 1 \qquad (11)$$

$$Qf.\left(1-\left[f/f_{\max}\right]^2\right) \le \frac{\Delta Q}{P} \le Qf.\left(1-\left[f/f_{\min}\right]^2\right) \qquad (12)$$

Q_f is the quality factor of the local load circuit and V_{max}, V_{min}, f_{max} and f_{min} represents the maximum and minimum frequency and voltage limits. For a current controlled interface the NDZ for the OFP/UFP remains the same as above but that of OVP/UVP protection turns out to be different as shown in (13)

$$\left[V/V_{\max}\right] - 1 \le \frac{\Delta P}{P} \le \left[V/V_{\min}\right] - 1 \qquad (13)$$

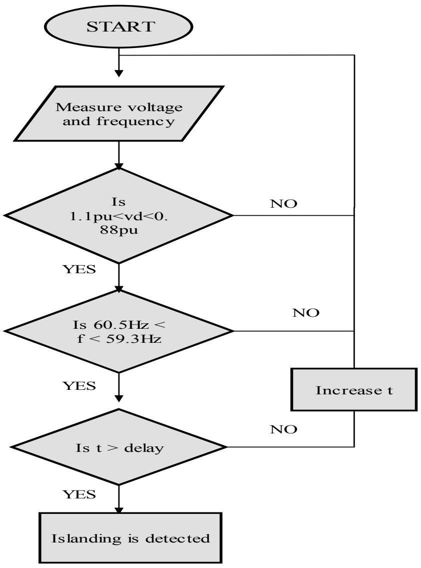


Figure.4.Islanding Detection Algorithm

IV. LOAD SHEDDING ALGORITHM

With the suggested islanding detection algorithm, some load generation mismatch is needed, for transferring the control from grid connected to islanded mode. But such a system cannot sustain an island due to the excessive variation of frequency and voltage. Hence, when the required demand is more, some load should be cut off using an efficient load shedding scheme, to prevent the voltage and frequency collapse. Here a priority based load shedding is implemented. The magnitude of the voltage at the PCC, obtained from the DQ PLL, is continuously measured. When it crosses the specified voltage level, specified in the algorithm shown in Fig.5, signal is given to the circuit breaker to remove the load. Load 2 is made to have more priority than load 1, and will not shut down until large voltage variation persists. [11]

The first voltage levels 0.15pu and 0.3pu corresponds to immediate trip of load 1 and load 2. The second voltage level 0.1pu triggers a load shedding command only when the voltage remains there for the specified time delay. T1 and T2 are the delay time for load 1 and load 2 respectively, where T2>T1

V. SIMULATION RESULTS AND DISCUSSION

The performance of the system in grid connected and islanding mode of operation is analyzed using the simulated system in MATLAB/SIMULINK. The simulated system is shown in Fig.6. The inverter is operating with unity power factor, delivering 10kW power to the load. The system parameters are given in table 1.

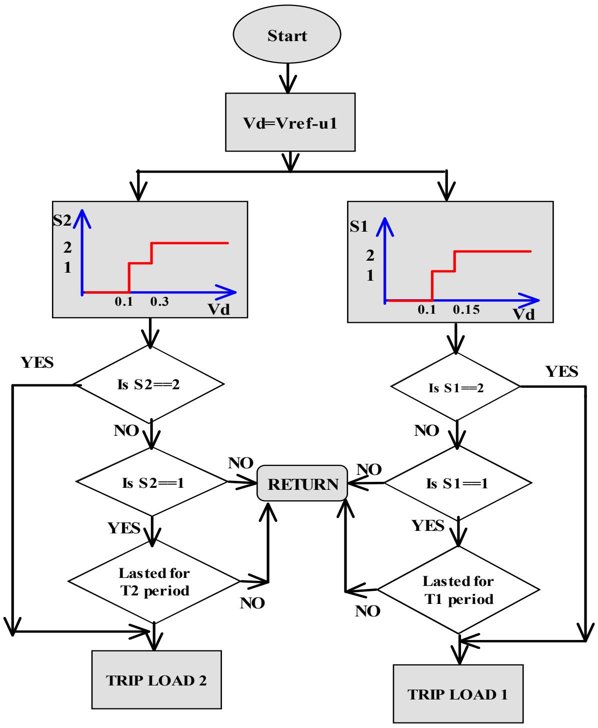


Figure.5.Load shedding Algorithm

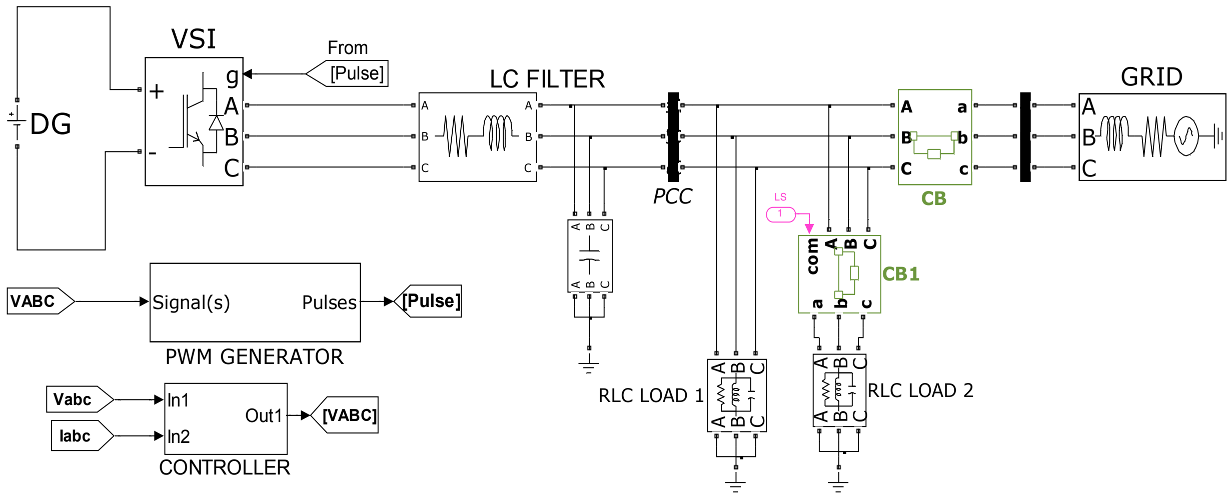


Figure.6.Simulated System

Grid gets disconnected at t=2sec.Designing the interface control as constant current controlled, four cases as analyzed.

Case1: Load is adjusted to operate the inverter at 100% active power (P) balance and 100% reactive power balance (Q)

Case2: Load is adjusted at 50% rated P and 100% Q balance

Case 4: Load at 100% rated P and 96.6% Q balance

Case 5: Load at 125% rated P and 103.4% Q balance.

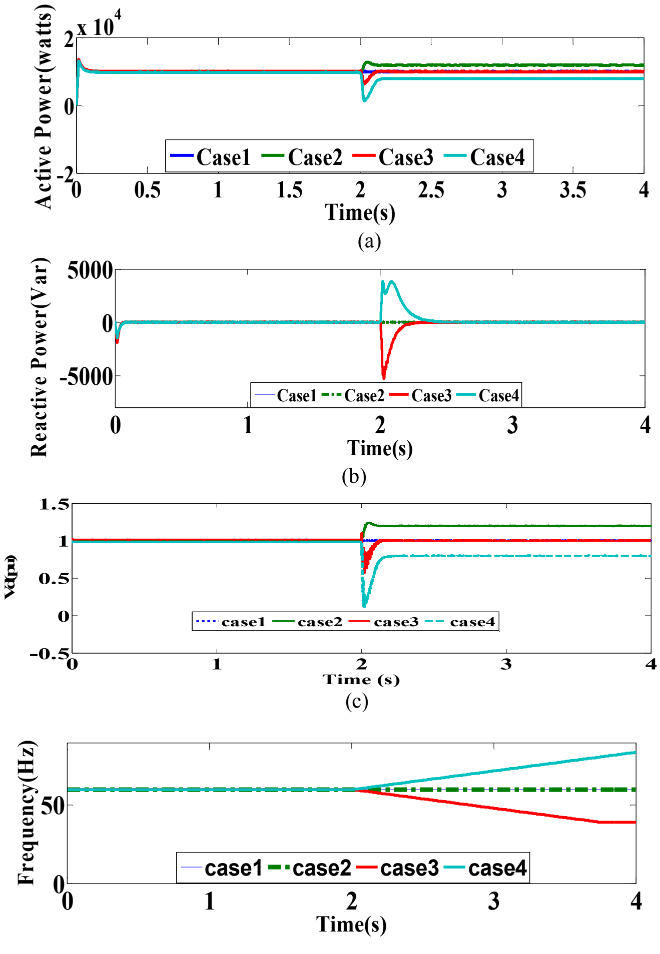
The simulated results are shown in Fig.7.With the above suggested islanding detection algorithm, only during case 4, islanding will be detected.

For a constant preset current output, once islanding occurs, the output power and voltage becomes a function of the load. It is also observed that, the performance of constant power controlled interface during islanding operation is different from the constant current controlled interface. The NDZ is shown in Fig.8

TABLE 1

SYSTEM PARAMETERS

INVERTER		**LOAD PARAMETERS**	
Switching frequency	10kHz	R2	4.33Ω
Input Dc voltage	400V	L2	4.584mH
Filter Inductance	4.2mH	C2	1.535mF
Filter Capacitor	31μF	R1	5.1838Ω
Voltage (Phase to ground)	120Vrms	L1	4.584mH
DG output power	10kw	C1	4.535mF
GRID PARAMETERS			
Frequency		60Hz	
Grid Inductance		0.05mH	
Grid resistance		0.02Ω	



(a)

(b)

(c)

(d)

Figure.7.Variation of (a) Active power (b) Reactive power (c) Magnitude of voltage at PCC in pu (d) Frequency in Hz for a current controlled interface before and after islanding

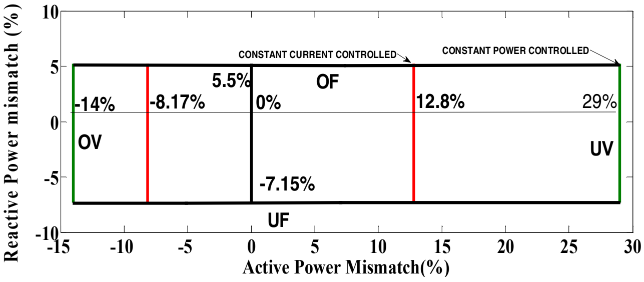


Figure.8. Simulated NDZ for constant current controlled interface and constant power controlled interface for OVP/UVP and OVF/UVF protection

Certain points which are noted from the results:

1) The NDZ for the constant power controlled interface is larger comparing with the current controlled interface.

2) NDZ for reactive power mismatch is less comparing with the active power mismatch. Reactive power variations are more sensitive and produce notable deviations in frequency to trigger islanding detection. When grid is not providing the desired reactive power, frequency varies, to reach the resonant frequency of the load.

3) With the specified islanding detection algorithm, both active and reactive power variations are needed for reliable detection. Large active power mismatch can produce frequency deviation in addition to voltage variation. But it wouldn't result in fast detection.

A. Grid connected to Islanded Mode

Islanding detection algorithm continuously monitors the variations in the frequency and voltage at the PCC. After the grid gets disconnected at t=2sec, the algorithm waits for the specified time delay and will give a switching command at 2.05sec. Load shedding algorithm works in parallel with the ID algorithm and check for the deviation in voltage. The load 1 will be cut off at 2.06sec and the system starts operating in the voltage control mode.

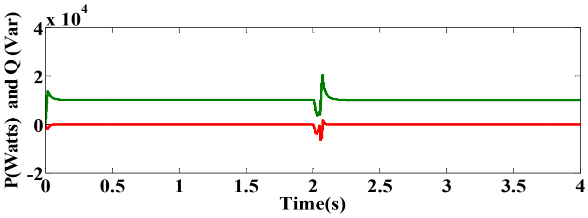


Figure. 9.Active and Reactive power variation

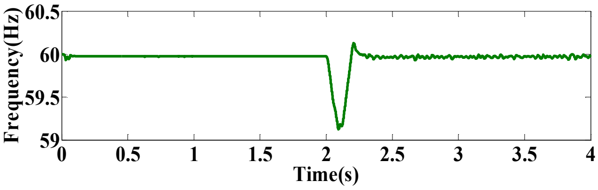


Fig. 10. Frequency of the voltage at PCC.

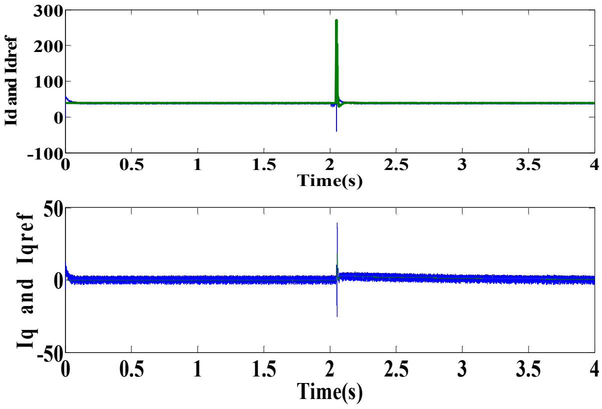


Figure 11: I_d and I_q tracking I_{dref} and I_{qref}

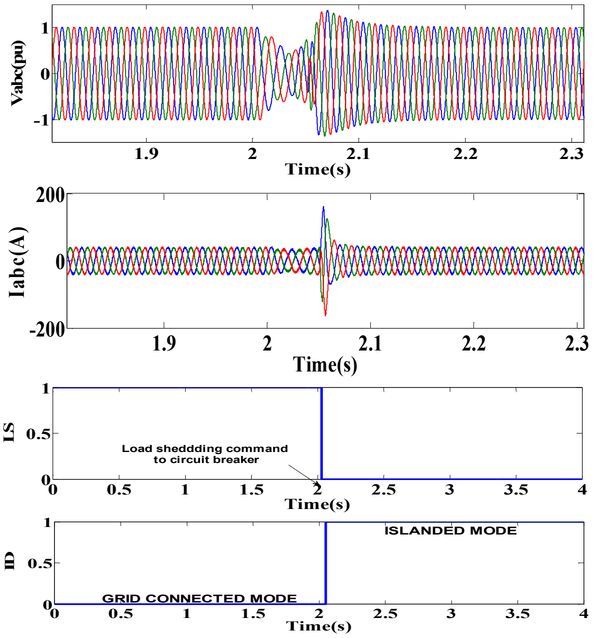


Figure. 12. (a)Three phase voltage at the PCC (b) Three phase current from the inverter (c) Command from the load shedding algorithm to shut down the load (d) Islanding detection algorithm output

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