Nitrogen Injection Fire Prevention System for Oil Filled Transformers

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ABSTRACT

Fire hazards occurring at power transformers and interconnecting transformer installation are the matter of serious concern. Different types of Transformers are used in power system. Commonly used power transformer is oil filled power transformer. In the oil filled power transformer oil act both as insulating and cooling media. During an internal fault resulting in an arc will cause fire. Fire hazards lead into serious consequences such as fatal or non-fatal accidents and loss of valuable assets. One power transformer costs to 4 Crores approximately. Moreover such types of incidents may cause fatal accidents to human beings or stray animals. The Nitrogen Injection Fire Prevention System (NIFPS) is an effective technique for quenching the fire. In the event of fire hazards, the system actuates and abolishes fire quickly.

Keywords: *Nitrogen Injection Fire Prevention System (NIFPS), Explosion, Tank Rupture, OIP Bushing, Differential relay, Buchholz relay, Master (86) relay.*

I. INTRODUCTION

The risk of a transformer causing a fire is low, but not negligible and the consequences can be very severe if it does occur. The aim of this paper is to promote "Good Fire Safety Practices". It endeavors to do this by:
(a) Discussing Fire Physics and Typical Transformer Fire Scenarios.
(b) Presenting typical transformer fire scenarios.
(c) Discussing Nitrogen Injection Fire Prevention System (NIFPS) which reduce the risk and consequences of a transformer fire.
(d) To present practical and cost effective strategies for fire prevention and for control and risk mitigation measures which can be applied to both transformers and transformer installations.

Avoidance of tank rupture and containment of oil is critical for limiting the consequences of a transformer failure and reducing the risk that a minor transformer fire escalates into a major or catastrophic oil fire. This paper therefore presents NIFPS as safety measure.

The probability of transformer fires are in the order of 0.1 % per transformer service year i.e. 1 fire per 1000 in service transformers per year. This is not a high probability, but the consequence is nearly always total loss of the transformer and often with collateral damage to other adjacent assets and often with some environmental pollution and loss of supply for various durations. Also whilst 0.1 % may appears low, the accumulated probability of the event happening is on average in the order of 4 % per transformer over a typical service life of 40 years. The risk is therefore not negligible and it is certainly too high to ignore and do nothing.

The probability of transformer fires varies considerably among utilities and even among types of transformers within the same utility. Some utilities have significantly higher and some significantly lower numbers of transformer fires than the average probability. Similarly some utilities may have types or voltage classes of transformers which have much higher probability of causing fires than others types.

When a transformer failure results in a fire the transformer will often be damaged to a degree where repair is not economic. The aim is therefore not to save the transformer if a transformer fire occurs, but rather:
(i) To prevent and minimize consequential damage to the substation installation and other plant items located in the

vicinity of the transformer on fire.

(ii) To avoid loss of supply from the substation and if not possible then to minimize the time of loss of supply.

(iii) To minimize and if possible avoid pollution and contamination to the surrounding environment, especially the environment outside the substation boundary. The potential pollution includes both airborne pollution in form of smoke, soot and noxious fumes and runoff causing ground water contamination by oil or other chemicals including foams and other fire-suppressant chemicals which may be used in firefighting.[1]

II. FIRE PHYSICS

Fires are depending of the control of heat energy, oxygen and fuel. The fire triangle provides very good graphic representation of what is required to initiate and maintain a fire and therefore also how a fire can be prevented or extinguished.

For a fire to exist and propagate, it requires the three key elements of Heat, Fuel and Oxygen in well-defined ratios.

(i) Without oxygen there will be no fire.
(ii)Without heat there will be no fire.
(iii)Without fuel there will be no fire.

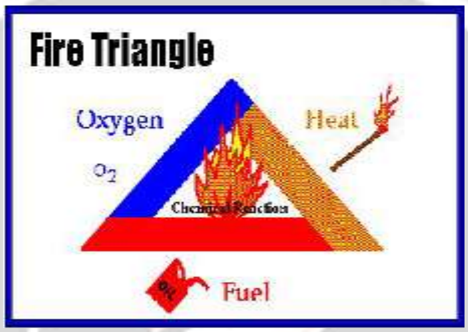

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Figure 1: Fire Triangle

If anyone of these three elements is absent then the fire will not start, or if removed after a fire has started then the fire will extinguish .It is therefore useful to consider the common ways heat can be produced in the context of transformer fire safety i.e. in addition to the heating produced from load and no load losses.

A. WHAT IS FIRE?

Fire is the common term for combustion which is the chemical reaction of oxidation, which happens when for example the organic compounds (Mineral oil in case of transformer) are combined with oxygen in air at a high temperature. The combustion is made up from a large number of chemical reactions in many steps. The first step is when the organic molecules are decomposed and many different gases are formed; including hydrogen, carbon oxide, methane and different alcohols. This first step is called pyrolysis and the gases have not yet reacted with the oxygen in air. The pyrolysis consumes energy, so heat has to be added from outside during this part of the process. The second step is when oxygen (from air) reacts with the gases from the pyrolysis and the process becomes exothermic (gives of heat), - this is combustion.[4]

III. EXTINGUISHMENT OF FIRES

The fire triangle listed in Fig.1 provides a very good graphic presentation of how a fire can be extinguished.

A. Remove the Heat (Cooling)

The fire can be extinguished if the heat is removed and the fuel is cooled below its fire point temperature. Water can be very efficient as a cooling medium to extinguish external fires and to protect adjacent asset from being heated to their flash point. Water is less efficient in extinguishing a fire burning inside a transformer, as it is often difficult to get the water into the transformer tank and the oil will float on the top of the water and continue burning even if water is sprayed in to a transformer tank. Also for the same reason water alone is not efficient in extinguishing oil pool fires. Whereas water with foam can be very efficient for this purpose as it excluded oxygen from the oil surface.

B. Oxygen displacement or dilution (Smothering)

Removal of oxygen can be a very effective method of extinguishing fires where this method is possible. Only a slight decrease of the oxygen concentration in air decreases the fire intensity and below 16 % oxygen in the air there is no

risk for a fire. Many alternative gases have been used successfully to displace or dilute oxygen and thus extinguish the fire. Gases commonly used for this purpose include carbon dioxide, halon and nitrogen. (Halon is now disappearing from use, as it is considered a non-environmentally friendly gas).
The disadvantage for CO2 gases has been that human beings could be suffocated, if the gas is injected before all humans have been evacuated. CO2 is heavier than air and is often used in buildings and other areas where the gas can be contained and the displaced air can raise above the fire.
Nitrogen is lighter than air and is uses for injection where the fire is at an upper surface and the nitrogen can be contained, as it can in a transformer tank. Some manufactures of transformer fire extinguishing systems, have used nitrogen for injection into the base of oil filled transformers to extinguishing a fire burning from the oil surface. In this application nitrogen will stir and cool the oil in the transformer tank and displace the air above the oil and suppress the fire.
Foam and high pressure water fogging can also be used to displace oxygen. Foam can be very effective for use on oil pool fires, but is less effective on oil fires where oil is spilling over a vertical surface and it is often difficult to get foam into a fire burning inside a transformer tank. Water deluge and high pressure water fog or water mist have the benefit of oxygen dilution as well as providing cooling.

C. Removal of fuel (Starvation)

Removal of fuel can be effective, but is often not possible. Some strategies for fuel removal exist for transformer oil, as it is possible to equip transformer tank with oil dump valves which can be opened by remote control. Dumped and/or spilled oil can be directed into oil/water separation tanks or into gravel or crushed rock beds or other safe holding areas. [1]

IV. TRANSFORMER FAILURE RATE FROM SURVEY DATA

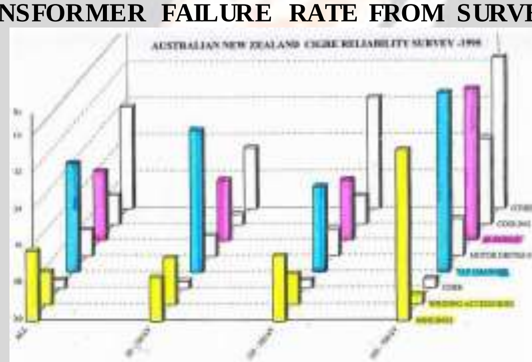

Fig 3: Transformer Failure Rate according to Component and Voltage level Australian New Zealand Reliability Survey

Voltage Class [kV]	Failure rate/year (%)	Fire incidence in % of failures	Fire incident rate /year (%)
735 (Transformers)	2.32	9.5	0.22
735 (Reactors)	3.15	11.4	0.36
315	0.84	21.9	0.18
230	0.49	15.8	0.08
161	0.50	0	0.00
120	0.6	2.6	0.02
Average	**1.21**	**8.38**	**0.14**

Table 1: Statistics by a major Canadian Utility 1965 -1985: Fire rate

From the data presented in Table 1,it can be concluded that the average failure rate is 1.2%, but the failure and fire incidence rates for the 735 kV class is much higher than for all other voltage classes.
The average fire incidence is 8.4% of all failures and the average fire incidence rate per year is 0.14%.

Voltage Class [kV]	Explosions	Major oil spill	Fires
735	15	9	8
315	3	2	1
230	2	1	1
161	0	0	0
120	5	3	3
Total	25	15	13

Table 2: Statistics by a major Canadian Utility 1965 -1985: Explosion vs. Fire

From the data presented in Table 2, it can be concluded that a high percentage [75%] of explosive failures (tank rupture) causes major oil spills and if there is an oil spill then there is also a high risk of a transformer fire.[6]

V. NITROGEN INJECTION FIRE PREVENTION SYSTEM

A. INTRODUCTION

Compared with water spray system, gas injection system has advantages such as reducing civil work at installation, no necessity of securing water, reducing piping installation, and so on. It should be noted that for an Inert Gas for Oxygen Displacement or a Hypoxic enclosure to provide effective fire protection, the enclosure must remain intact. So pressure venting may be required to ensure that the enclosure is not breached by the transformer failure event.

Gas injection systems have in the past been using CO2 or halon, but these gases have potential of attack to ozone layer and also have physiological influences. So today, from the view point of the global environmental protection and safety for human beings, the inert gas applied for fire protection of power transformers is now mainly nitrogen and also sometimes a mixture gas of Nitrogen, Argon, and CO2, Nitrogen is a cost effective and readily available gas.

As an example, when nitrogen gas is discharged to extinguish a fire, the concentration of nitrogen gas and oxygen gas in the room will charge to about 87% (normally 78%) and 12.5% (normally 21%) by volume respectively, according a supplies data. This means that oxygen concentration can be reduced from 21% to 12.5% within 1 minute after start of discharge. Continuous combustion requires more than 15% of oxygen concentration by volume, so the above data shows that the gas mixture as stated above is effective for fire suppression.

For application on power transformers where sound insulation panels are installed the panel enclosure can be used as outer enclosure for the gas containment for the fire suppression.

It is required than any ventilation provided on the sound enclosure if fitted with dampers which closes during the gas injection and remains closed until the fire extinguishing is completed.

If there is no sound insulation enclosure, then an additional enclosure will be necessary.
Figure 2 shows a diagrammatic presentation of a gas protection system.[5]

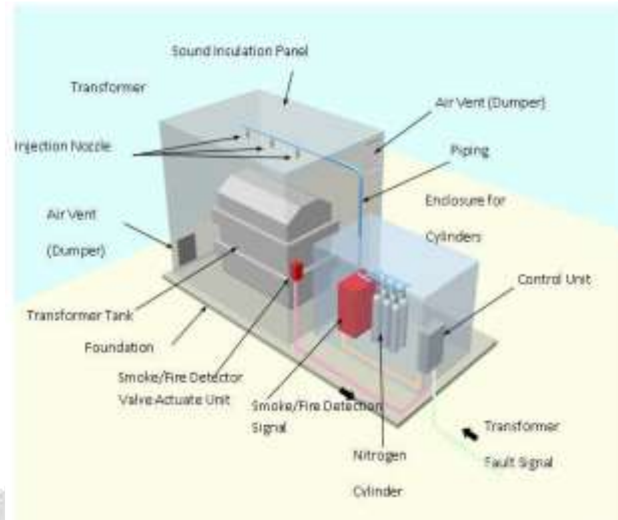

Fig 2: Nitrogen Injection Fire Prevention System

B. PRINCIPAL OF OPERATION

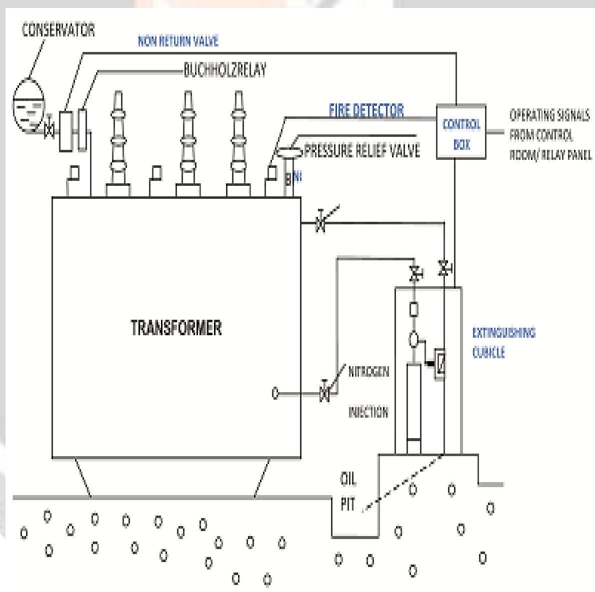

Fig 3: Block Diagram of Nitrogen Injection Fire Prevention System

Inert gas is injected into the enclosure by smoke detection signal and transformer fault detection signal. Selection and combination of trigger signal depends upon each user's practice and they are formed AND gate circuit for alarm evacuation. Transformer fault detection signal can be pressure relief device or Buchholz Relay.

C. OPERATION

Fig 4: Constructional details of Nitrogen Injection Fire Prevention System

On receipt of all activating signals, the system drain pre-determined volume of hot oil from the top of tank (i.e. top oil layer), through outlet valve, to reduce tank pressure by removing top oil and simultaneously injecting nitrogen gas at high pressure for stirring the oil at pre-fixed rate and thus bringing the temperature of top oil layer down. Transformer conservator isolation valve blocks the flow of oil from conservator tank in case of tank rupture / explosion or bushing bursting. Nitrogen occupies the space created by oil drained out and acts as an insulating layer over oil in the tank and thus preventing aggravation of fire. Being important protection equipment, system should have facility to operate i.e. both oil drain and nitrogen release, without power and also in case of failure of DC power. The system is able to run on line i.e. when transformer is energized by simulating oil drain and nitrogen release mechanism. [5]

D.ACTIVATION OF FIRE PROTECTION SYSTEM

Mal-functioning of transformer explosion prevention and fire extinguishing system could lead to interruption in power supply. NIFPS system ensures that the probability of chances of malfunctioning of NIFPS system is practically zero. To achieve this objective, the NIFPS System's scheme of activating signals is simple which is not too complicated to make the NIFPS system inoperative in case of actual need. The system is provided with automatic control for explosion prevention and fire extinction. Besides automatic control, remote electrical push button/switch control covered with glass at Control box and local manual control in the fire extinguishing cubicle shall also be provided. The following electromechanical signals are taken for activating the NIFPS system under prevention mode / fire extinguishing mode.

1) AUTO MODE:

a) For explosion prevention:

(i)Differential relay operation

(ii)Buchholz (Surge) relay trip paralleled with pressure relief valve or RPRR (Rapid Pressure Rise Relay)

(iii)Master (86) relay operation

b) For extinguishing fire:

(i)Fire detector

(ii)Buchholz (Surge) relay trip paralleled with pressure relief valve or RPRR (Rapid Pressure Rise Relay)

(iii)Master (86) relay operation

2) MANUAL MODE (Remote electrical)

Master (86) relay operation associated with transformer / reactor is the pre-requisite for activation of system.

3) MANUAL MODE (Remote mechanical)

The system shall be designed to be operated manually to release oil and inject nitrogen in case of failure of power supply to fire protection system. System shall have provision for independent oil drain and nitrogen release mechanism. [5]

E. SYSTEM COMPONENTS

Nitrogen injection fire protection system shall broadly consist of the following components. However, all other components which are necessary for fast reliable and effective working of the fire protective system shall be included in the system manufacturer scope of supply.

The system shall work on station DC supply only. Individual system component/equipment should not have working voltage other than station DC voltage. AC-DC / DC-DC converter, timer shall not be used for reliable operation.

a) Fire Extinguishing Cubicle (FEC)

The FEC frame is be made of CRCA sheet of 3 mm (maximum) thick complete with the base frame, painted inside and outside with post office red color (shade 538 of IS-5). It has hugged split doors fitted with high quality tamper proof lock. The degree of protection shall be IP55 for whole assembled Fire Extinguishing Cubicle. The following minimum items are to be provided in the FEC.

i) Nitrogen gas cylinder with regulator and falling pressure electrical contact manometer for monitoring cylinder pressure and pressure gauge after regulating pressure for monitoring nitrogen injection pressure.
ii) Oil drain pipe with mechanical quick drain valve of minimum size 125 mm for transformer rated 100 MVA and above, minimum 80 mm for transformer rated below 100 MVA.
iii) Electro mechanical control equipment for draining of oil of pre-determined volume and injecting regulated volume of nitrogen gas.
iv) Pressure monitoring switch for back-up protection for nitrogen release.
v) Individual mechanical locking devices for oil drain and nitrogen release to isolate the system during maintenance and /or testing of the transformer and /or system.
vi) Individual mechanical release devices for oil drain and nitrogen release to operate system manually in case of operation DC supply failure.
vii) System nitrogen release scheme shall be designed in such a way that the nitrogen gas shall not enter the energized transformer tank even in case of passing/leakage of valve.
viii) Limit switches for monitoring of the system
ix) Butterfly valve with flanges on the top of panel for connecting oil drain pipe and nitrogen injection pipes for transformer/reactors
x) Panel lighting (CFL Type)
xi) Oil drain pipe extension of 150mm size for transformer rated 100 MVA and above, 100 mm for transformer rated below 100 MVA. s for connecting pipes to oil pit.

b) Control box

Control box which to be placed in the control room for monitoring system operation, automatic control and remote operation. The following alarms, indications, switches, push buttons, audio signal etc. are provided.

System and / or individual component shall be designed to work on station DC voltage only and AC-DC/DC-DC convertor; timers shall not be used for reliable operation.

i) System on
ii) Oil drain valve closed
iii) Gas inlet valve closed
iv) TCIV closed
v) Fire detector trip
vi) Buchholz (surge) relay trip
vii) Oil drain valve open
viii) Extinction in progress
ix) Cylinder pressure low
x) Differential relay trip
xi) PRV / RPRR trip
xii) Master (86) relay of transformer / reactor trip
xiii) System out of service
xiv) Fault in cable connecting fault fire detector
xv) Fault in cable connecting differential relay
xvi) Fault in cable connecting Buchholz relay

xvii) Fault in cable connecting PRV / RPRR
xviii) Fault in cable connecting transformer /reactor trip
xix) Fault in cable connecting TCIV
xx) Switch : Auto/ Manual / Off
xxi) Switch : Extinction release on / off
xxii) Push Button : Lamp test
xxiii) Visual/ Audio alarm
xxiv) Visual/ Audio alarm for DC supply fail

c) Transformer Conservator Isolation Valve

Transformer conservator isolation valve (TCIV)which is to be fitted in the conservator pipe line, between conservator and buchholz relay shall operate for isolating the conservator during abnormal flow of oil due to rupture / explosion of tank or bursting of bushing. The valve will not isolate conservator during normal flow of oil during filtration or filling or refilling, locking plates are provided with handle for pad locking. It has proximity switch for remote alarm, indication glass with visual closed position indicator similar like buchholz relay glass inspection window for physical checking of the status of valve.

The TCIV are of the best quality as malfunctioning of TCIV could lead to serious consequence. The closing of TCIV means stoppage of breathing of transformer/reactor.

Locking plates are provided for pad locking with handle to keep TCIV out of service mode. Locking plates shall provide pad locking along with padlock.

d) Fire detectors

The system will be complete with adequate number of fire detectors 141˚C (quartz bulb) fitted on the top cover of the transformer / reactor oil tank for sensing fire and shall be located at strategic locations specifically bushings/cable box, OLTC, PRV etc

e) Signal box

The box supplied shall be mounted away from transformer / reactor main tank, preferably near the transformer marshalling box, for terminating cable connections from TCIV & fire detectors and for further connection to the control box. The degree of protection shall be minimum IP55.

f) Cables

Survival cables (capable to withstand 750° C.) of 4 core x 1.5 sq. mm size for connection of fire detectors in parallel are supplied to be used for connecting Fire Detectors. The fire survival cable shall conform to BS 7629-1, BS 8434-1, BS 7629-1 and BS 5839-1, BS EN 50267-2-1 or relevant Indian standards.

Fire Retardant Low Smoke (FRLS) cable of 12 core x 1.5 sq. mm size are supplied to be used for connection of signal box / marshalling box near transformer/reactor and FEC mounted near transformer/reactor with control box mounted in control room.

Fire Retardant Low Smoke (FRLS) cable of 4 core x 1.5 sq. mm size are supplied to be used for connection between control box to DC and AC supply source, fire extinguishing cubicle to AC supply source, signal box/ marshalling box to transformer conservator isolation valve connection on transformer/reactor.

g) Pipes

Pipes complete with connections, flanges, bends and tees etc. shall be supplied along with the system. [5]

F. TECHNICAL SPECIFICATIONS

Fire extinction period from commencement of nitrogen injection	30 secs.(Max.)
Fire extinction period from activation of system	3 minutes (Max.)
Fire detector's (quartz bulb) heat sensing temperature	141˚C
Heat sensing area per detector	Up to radius of 800 mm

Transformer Conservator Isolation valve setting	60 ltr / min (Minimum)
Capacity of nitrogen cylinder	68 ltr (Minimum) water capacity and shall hold 10 m^3 (Minimum)gas at maximum pressure of 150 kg/cm^2
Power supply For Control Box For Fire extinguishing cubicle for lighting	 220 V / 110 V DC 230V AC

[5]

G. MAINTENANCE

Practically Nitrogen Injection and Drain method of Fire Protection and Extinguisher system is maintenance free.

It is recommended for monthly visual inspection for about 15-20 minutes and annual operational test schedule.

H. ADVANTAGES OF Nitrogen Injection Fire Prevention System (NIFPS)

i) Low investment cost as compared to other conventional system.
ii) Very low post fire and no secondary damages.
iii) Minimum maintenance and running cost.
iv) No climatic effects.
v) Suitable for indoor / outdoor installation.
vi) Minimum space requirement.
vii) Multi signals for activation, eliminates false alarms.
viii) Allows system testing on operational transformer not possible with conventional fire system.
ix) No moisture absorbing in inside the transformer due to presence of nitrogen.
x) Great saving in cost, due to absence of moisture.
xi) Fully automatic, unattended and a fool proof system.
xii) It can be operated manually / automatically, local / remote control.
xiii) No water reservoir or major civil work required.
xiv) Prevents transformer explosion ensuring system remains functioning.
xv) Prevention of unplanned outages.
xvi) Considerable savings.
xvii) Improves overall power system reliability.

VI. CONCLUSION

Safety of power transformers, reactors and interconnecting transformer installations are of matter of serious concern. Fire hazards lead into serious consequences such as fatal or non-fatal accidents and loess of valuable assets. NIFPS is satisfactorily adopted by major state electricity boards.

Nitrogen Injection Fire Prevention System (NIFPS) is the traditional method of quenching the fire hazards occurring at transformer installation. NIFPS is suitable for outdoor as well as indoor transformer installations, due to:

i) Low investments
ii) Low maintenance
iii) Practically no running cost
iv) "Fool proof operation.

The following comparison explains reasons for choosing Nitrogen Injection Fire Prevention System (NIFPS):

Comparision				
Sl. No.	Item	Nitrogen	Water	CO_2
1.	Purpose	Fire Prevention, Fire Extinction	Fire Extinction	Fire Extinction
2.	Principle	Release of excess pressure by oil drain cooling of top oil surface below flash point by stirring	Cooling O_2 Seal off	Reduction of O_2 contents
3.	Installation	Indoor / Outdoor	Outdoor	Indoor
4.	Space requirement	Small	Great	Great
5.	Civil Work	Minor	Major	Medium
6.	Climatic influence	None	Freezing of water	None
7.	Human Danger	None	None	Suffocation
8.	Secondary damages	No secondary damages	Paper insulation Transformer burnt out	Contamination by carbon components
9.	Investment	Low	Very high	High
10.	Maintenance	Very low	Extensive	Low
11.	Running cost	Practically nil	Very high	High

Fig 5: Comparison of different fire extinguishing systems

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