Transformer fault diagnosis using Dissolved Gas Analysis technology and Bayesian networks

A. Lakehal, Z. Ghemari, and S. Saad

Abstract— **Bayesian model is developed for transformer faults diagnosis using dissolved gas in oil analysis. DGA (Dissolved Gas Analysis) is the traditional and conventional transformer fault diagnosis method, which mainly depends on the experience of operators and of the percentages of dissolved gases. In addition, the only measurement of the gases percentage is not sufficient to evaluate the equipment health. There are several cases where the proportions of dissolved gases remain trapped in the transformer. Regarding this uncertainty and in order to make decisions in a certain environment, the model developed in this study represents a powerful tool for decision making. In addition, one traditional method of DGA does not enable the diagnosis of all faults, for example the Rogers Ratio Method diagnose five faults only, but using the proposed Bayesian network (BN) it is possible to diagnose all faults from the same model. To illustrate the advantages of Bayesian methods in transformer fault diagnosis, a study of power station main transformer is conducted and the results are analyzed and discussed.**

I. INTRODUCTION

The transformer is the most important equipment in a power plant. The main concern for maintenance managers is to ensure optimal availability of this equipment. In the field of power distribution, the transformer is an omnipresent element, its failure influences directly he continuity of service. Thus in order to optimize the availability of this equipment rigorous monitoring of its behavior and an effective supervision must be carried out.

Dissolved gas analysis (DGA) is the most common technique used to monitor and diagnose transformer health. Each gas has a percentage, and each percentage should not exceed a limited value. Each anomaly gives a gas or a mixture of gas with different proportions, the proportions percentage depends on the anomaly nature [1]. The analysis technique of dissolved gas is based on traditional (conventional) methods of faults diagnosis such as, Key Gas Method, Dornenburg Ratio Method, Rogers Ratio Method, Method nomograph, IEC Ratio Method, Duval Triangle Method, and CIGRE Method [2]. Recently, artificial intelligence methods have been introduced to improve the

Abdelaziz Lakehal is with Department of Mechanical Engineering, Mohamed Chérif Messaadia University, P.O. Box 1553, Souk-Ahras, 41000, Algeria, and with Laboratoire Systèmes Electromécaniques (LSELM), University of Badji-Mokhtar Annaba, 23000, Algeria (lakehal21@yahoo.fr).

Zine Ghemari is with Electrical Engineering Department, University of M'sila, M'sila, Algeria, and with Laboratoire Systèmes Electromécaniques (LSELM), University of Badji-Mokhtar Annaba, 23000, Algeria (ghemari-zine@live.fr).

Salah Saad is with Laboratoire Systèmes Electromécaniques (LSELM), University of Badji-Mokhtar Annaba, 23000, Algeria (saadsalah2006@yahoo.fr).

results accuracy and remove the inherent uncertainty in the diagnosis and data reliability (Fuzzy Logic (FL), Artificial Neural Networks (ANN), Support Vector Machine (SVM), Evolutionary Algorithms and Expert System) [3].

The literature shows that in recent years, many reported works were carried out using the combination of two or more methods of artificial intelligence to better diagnose the causes of transformer faults. Combining ANN with expert system for transformer fault diagnosis [4], SVM, ANN and clonal selection algorithms optimization [5], and a model based on the SVM method and genetic algorithm [6].

This paper focuses on the transformer fault diagnosis using Bayesian network (BN). The BNs are artificial intelligence tools which can be employed for faults prediction and diagnosis. Using a BN, the probability of oil breakdown voltage drop as a function of the water content can be quantified [7]. BNs are based primarily on experimental data by using DGA to define the network parameters. They also depend on the experience feedback of maintenance staff operators to mount equipment failures various scenarios, and consequently to define the network structure.

II. BAYESIAN NETWORKS

Probabilistic graphical models such as BNs [8] have been widely used to solve various problems (for example, diagnosis, anomalies prediction and risk analysis) [7,9]. These models are characterized by their ability to treat uncertain information and represent the interdependencies between different variables of a given problem. The advantage of probabilistic graphical models is interesting graphical representation of models, easy to understand and analyze. In addition, the probabilistic failure analysis evaluates the probability of fault of a complex system that its weak points can be identified.

In Bayesian methods, *a priori* information, the likelihood and the *a posteriori* information are represented by probability distributions. Thus, *a priori* probability represents the probability distribution of knowledge or belief concerning a subject or a variable before the parameter it represents is observed. The likelihood is a parameter function of a statistical model, reflecting the possibility of observing a variable when these parameters have a value. *A posteriori* probability is the conditional probability on collected data by a combination of *a priori* probability and likelihood through Bayes' theorem [10].

In a BN, an edge between two variables implies a direct dependence between these two variables: one is the parent and the other is the child. It must provide the behavior of the child variable regarding the behavior of its Parents (if there

Transformer fault diagnosis using Dissolved Gas Analysis technology and Bayesian networks

Abdelaziz Lakehal
Mohamed-Cherif Messaadia University - Souk Ahras
Laboratoire des systèmes Electromécanique L.S.E.L.M
(Annaba University)

April 28-30, 2015, Sousse, Tunisia

Outline

- ## Introduction
- ## Transformer fault diagnosis
  - Motivation
  - Problem formulation
- ## Construction of Bayesian network
  - Definition and advantage
  - What ingredient
- ## Model development and case study
- ## conclusion and futur work

Agenda

- **Introduction**
- Transformer fault diagnosis
  - Motivation
  - Problem formulation
- Construction of Bayesian network
  - Definition and advantage
  - What ingredient
- Model development and case study
- conclusion and futur work

The transformer is an omnipresent equipment

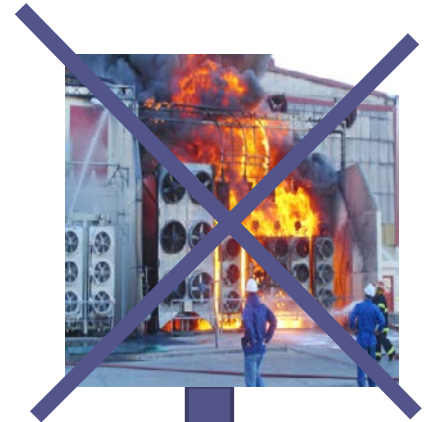**Its failure influences the continuity of supply**

Vital and not redundant

Optimize the availability

Rigorous monitoring of its behaviour

Predictive maintenance

Dissolved gas analysis (DGA)

Dissolved gas analysis (DGA)

➢ Each gas has a percentage

➢ Each percentage should not exceed a limited value

➢ Each anomaly gives a gas

➢ A mixture of gas with different proportions

➢ The proportions percentage depends on the anomaly nature

Traditional (conventional) methods

➢ Key Gas Method
➢ Dornenburg Ratio Method
➢ Rogers Ratio Method
➢ Method nomograph
➢ IEC Ratio Method
➢ Duval Triangle Method
➢ CIGRE Method

Artificial intelligence methods

➢ Fuzzy Logic (FL)
➢ Artificial Neural Networks (ANN)
➢ Support Vector Machine (SVM)
➢ Evolutionary Algorithms
➢ Expert System

Bayesian networks tools

Agenda

- Introduction
- **Transformer fault diagnosis**
  - **Motivation**
  - Problem formulation
- Construction of Bayesian network
  - Definition and advantage
  - What ingredient
- Model development and case study
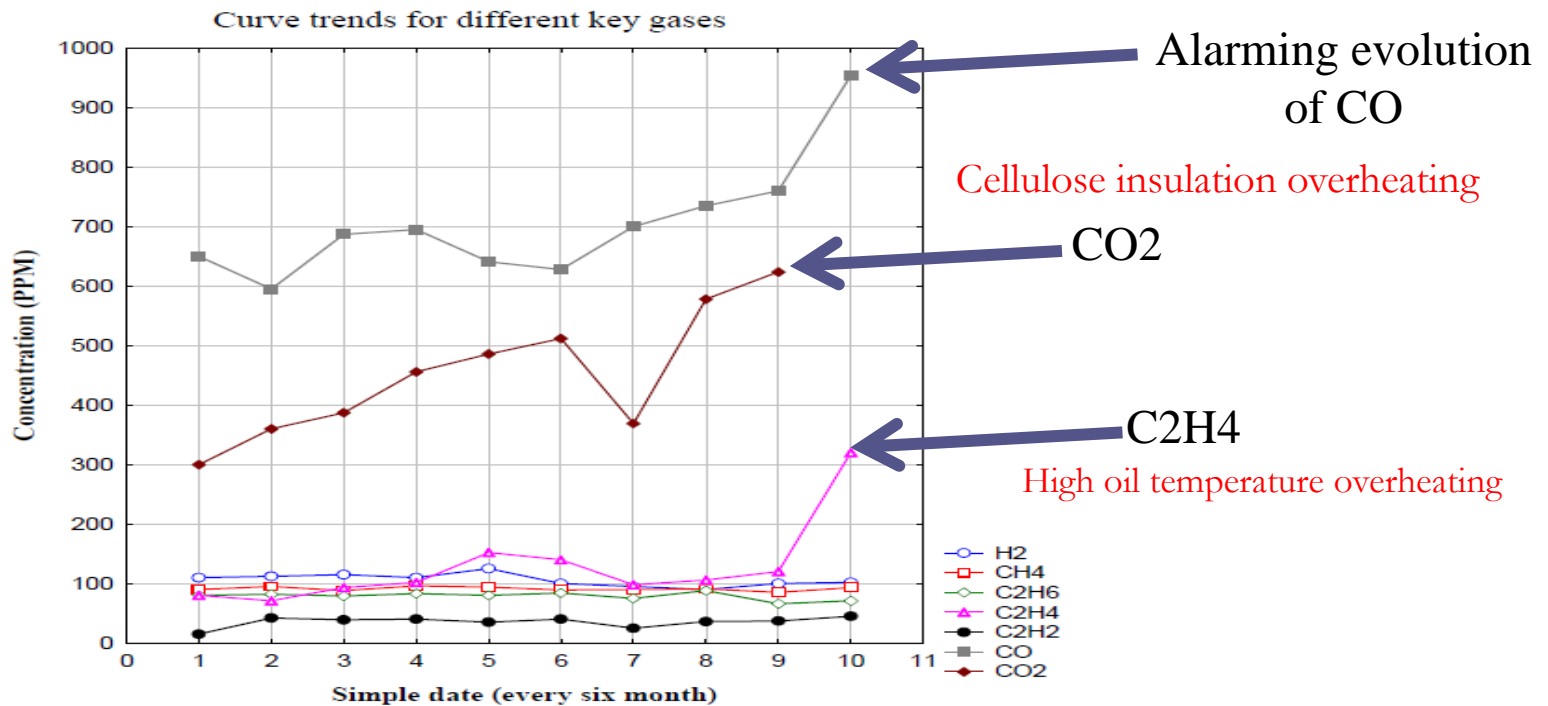- conclusion and futur work

Abnormal electrical or thermal stresses cause insulation oil to break down and to release small quantities of gases

DGA technology allows early fault detection and prevents other failures occurrence.
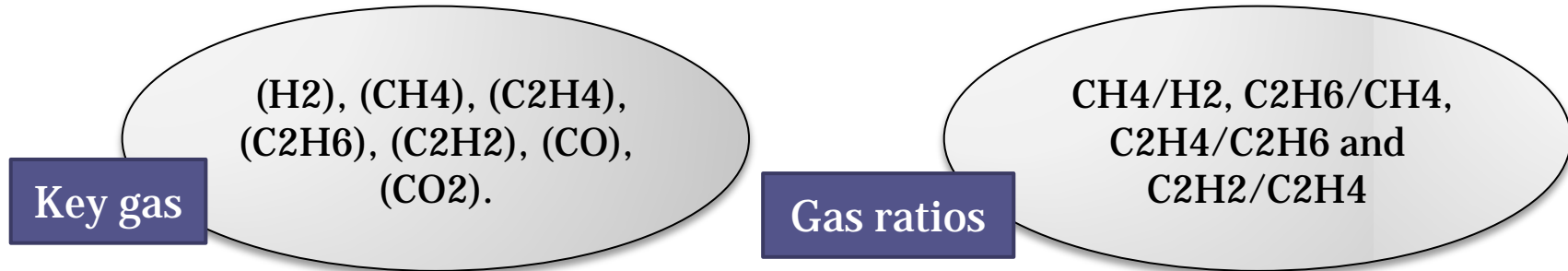
Various gases concentrations ➤ ▪**Type of fault : Thermal or electric**
▪**Fault severity**

Curve trends for different key gases

Alarming evolution of CO

Cellulose insulation overheating

CO2

C2H4

High oil temperature overheating

Traditional methods of DGA provide more details on fault nature by the use of ratios.

Key gas: (H2), (CH4), (C2H4), (C2H6), (C2H2), (CO), (CO2).

Gas ratios: CH4/H2, C2H6/CH4, C2H4/C2H6 and C2H2/C2H4

The existence of a gas is not always the result of a fault. In practice, there are several cases where gases are found but no fault is observed on the transformer; that is the case when gases remain trapped in the transformer.

DGA interpretation schemes are based on empirical assumptions and practical knowledge gathered by experts worldwide.

Agenda

- Introduction

- **Transformer fault diagnosis**
  - Motivation
  - **Problem formulation**
- Construction of Bayesian network
  - Definition and advantage
  - What ingredient
- Model development and case study
- conclusion and futur work

For what reason we will use the Bayesian network?

Reliability of data :
- Non-compliance with sampling instructions
- There are several cases where the proportions of dissolved gases remain trapped in the transformer.

Effectiveness of the method :
- One traditional method of DGA does not enable the diagnosis of all faults
  Rogers ratio method diagnoses only four faults
- When several gas ratios occur, the problem becomes a problem of decision making

If interpretation schemes are not applied cautiously, they may incorrectly identify faults because they only indicate possible faults.

In some cases, DGA interpretation schemes may differ in terms of identified faults, which is clearly unacceptable for a reliable fault diagnosis system.

Agenda

Definition:

Bayesian network is defined by a directed acyclic graph (DAG). Where C (Vi) is the set of parents (or causes) of Vi in DAG.


The relationship between the nodes of the network is given by the following formula

$$p(V_1, V_2, \ldots, V_n) = \prod_{i=1}^{n} p(V_i / C(V_i))$$

A Bayesian network for what?

- Knowledge modeling in an uncertain domain

- A simple graphical representation

- A large variety of uses

- A Bayesian network is a tool allowing the visualization of variables and their dependencies (or independences)

- One model → multiple uses :

    o Prediction (variables influenced by those which are known)

    o Diagnosis ("guess" the variables that influence those which are known)
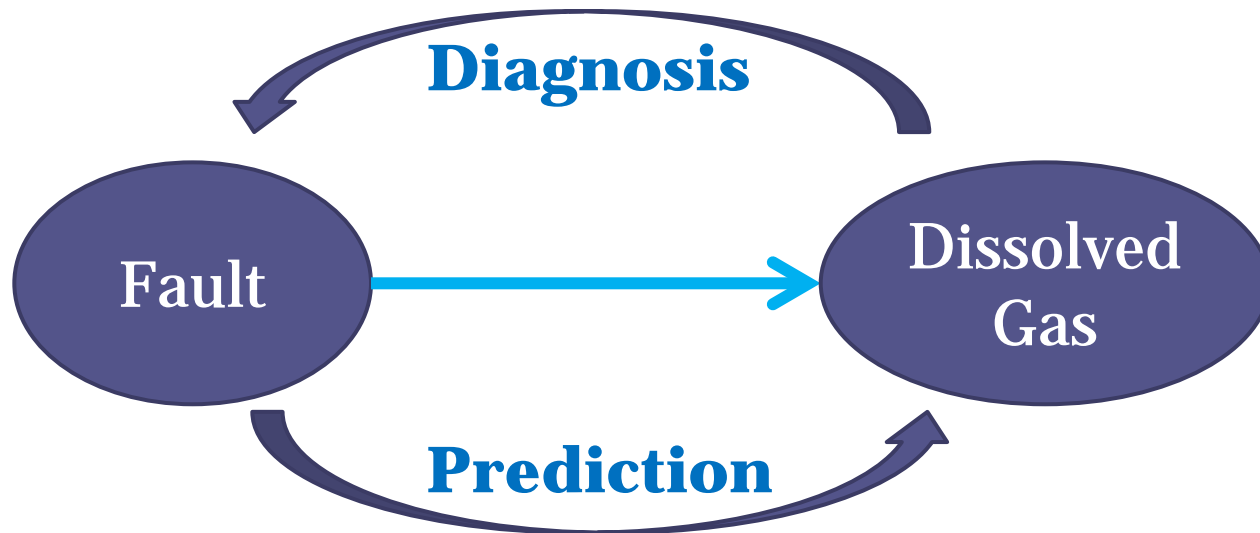
Diagnosis

Fault → **Dissolved Gas**

Prediction

Agenda

- Introduction
- Transformer fault diagnosis
  - Motivation
  - Problem formulation
- **Construction of Bayesian network**
  - Definition and advantage
  - **What ingredient**
- Model development and case study
- conclusion and futur work

▪the random variables are modeled as nodes

▪The edges between variables can explain a causal phenomenon (causal networks)

▪Indicating an edge between two variables implies a direct dependence between these two variables: one is the parent and the other is the child

Parent (Fault) → Child (Dissolved Gas)

▪To provide the behaviour of the child variable in view of the behaviour of his (or her if there are several) parents, each node has a conditional probability table.

▪A conditional probability table associated with a node allows to quantify the effect of the parent nodes on this node.

▪For root nodes (without parents), the probability table is not conditional and it fixed a priori probabilities.

▪ The Bayesian inference is to update the probability distribution to account for the new observations.

Agenda

- Introduction
- Transformer fault diagnosis
  - Motivation
  - Problem formulation
- Construction of Bayesian network
  - Definition and advantage
  - What ingredient
- Model development and case study
- conclusion and futur work

Defining the structure of the BN is to identify the different types of faults associated with different key gases .

The second step is to find firstly the causal links between faults and key gases, and secondly between key gases and ratios, because ratios gases exist only if key gases exist.

The third step is to define the probabilities of occurrence of each fault based on the results of oil analysis and experience feedback.

$$p(Ratio_1) = \prod_{i=1}^{2} p(Ratio_i \, / \, Keygaz_i)$$
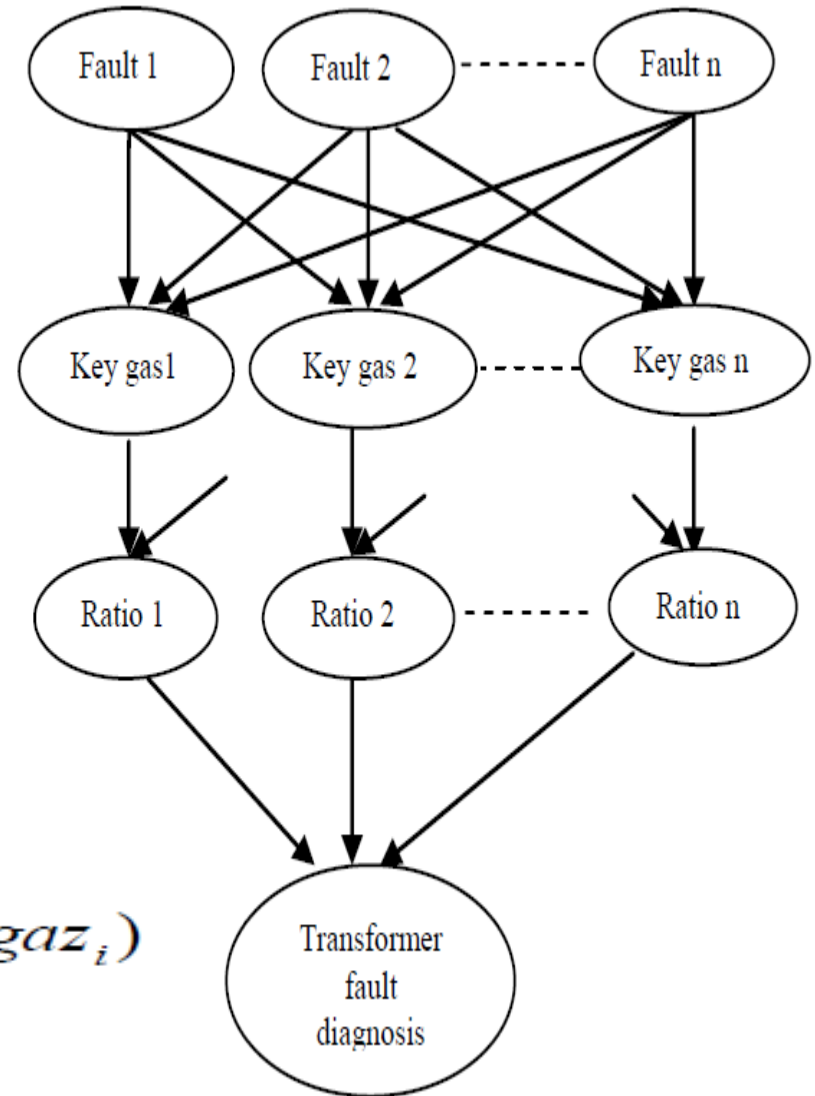
The most common gas ratio method is the Rogers ratio method

The Rogers method analyzes four gas ratios: CH_4/H_2, C_2H_6/CH_4, C_2H_4/C_2H_6 and C_2H_2/C_2H_4.

The four detectable conditions of an oil-insulated transformer are normal ageing, partial discharge with or without tracking, and electrical and thermal faults of varying severity.

Fault	Key gas or Ratio gas	Code
Overheating of cellulose insulation	CO, CO_2	F1
Electric discharge (corona effect, low partial discharge)	H_2	F2
Electric fault (arc, spark, partial discharge with or without tracking)	C_2H_2, CH_4, C_2H_4/C_2H_6, C_2H_6/CH_4	F3
Thermal fault (low temperature overheating (150 to 300 °C), middle temperature overheating (300 to 700 °C) and high temperature overheating (700 °C).	C_2H_4, C_2H_6, C_2H_2/C_2H_4	F4
Normal ageing	CH_4/H_2	F5
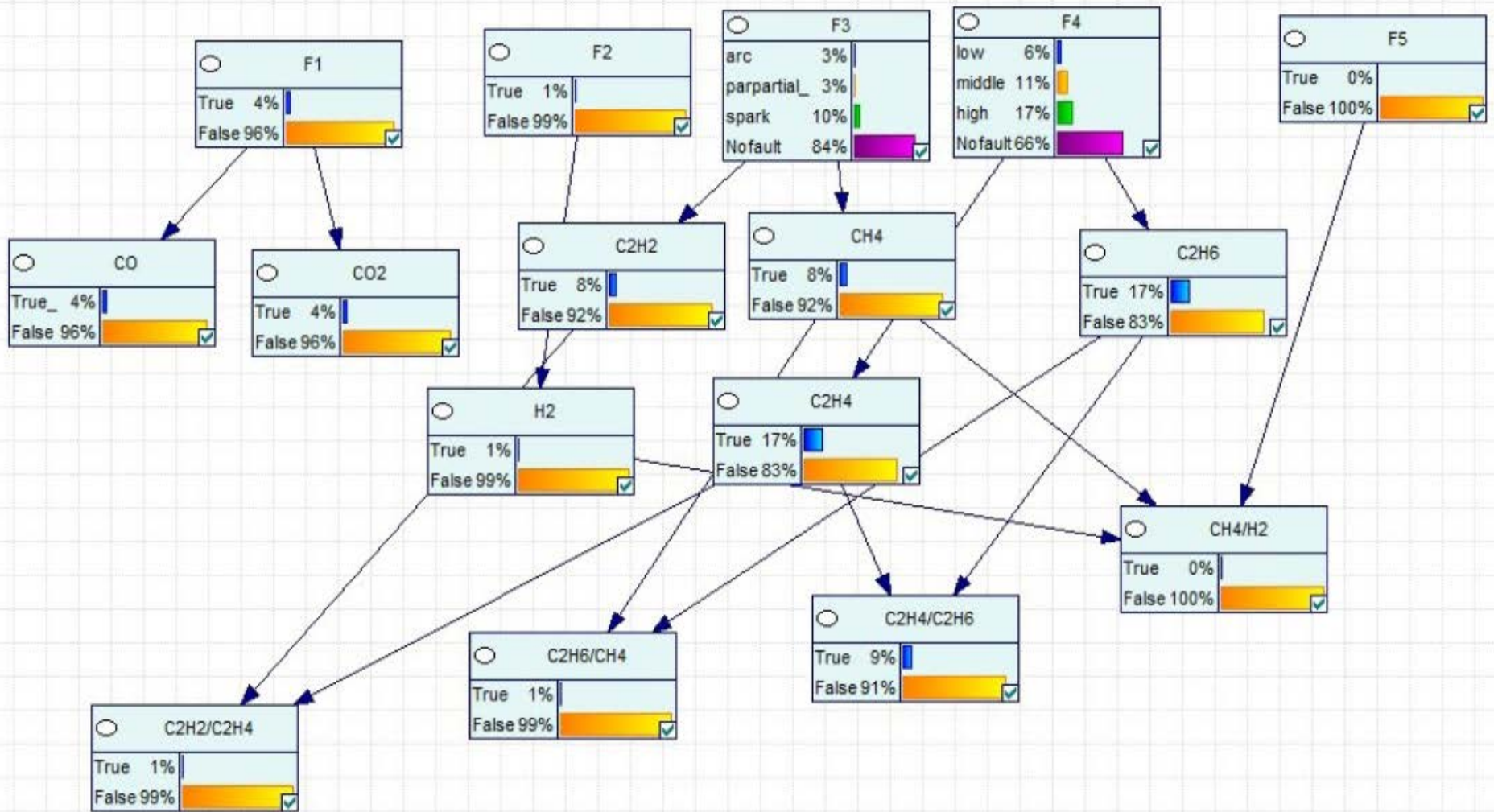
Ratio gas	Value	Fault type
C_2H_2/C_2H_4	0.008	low or middle temperature overheating
CH_4/H_2	1.6	
C_2H_4/C_2H_6	1	
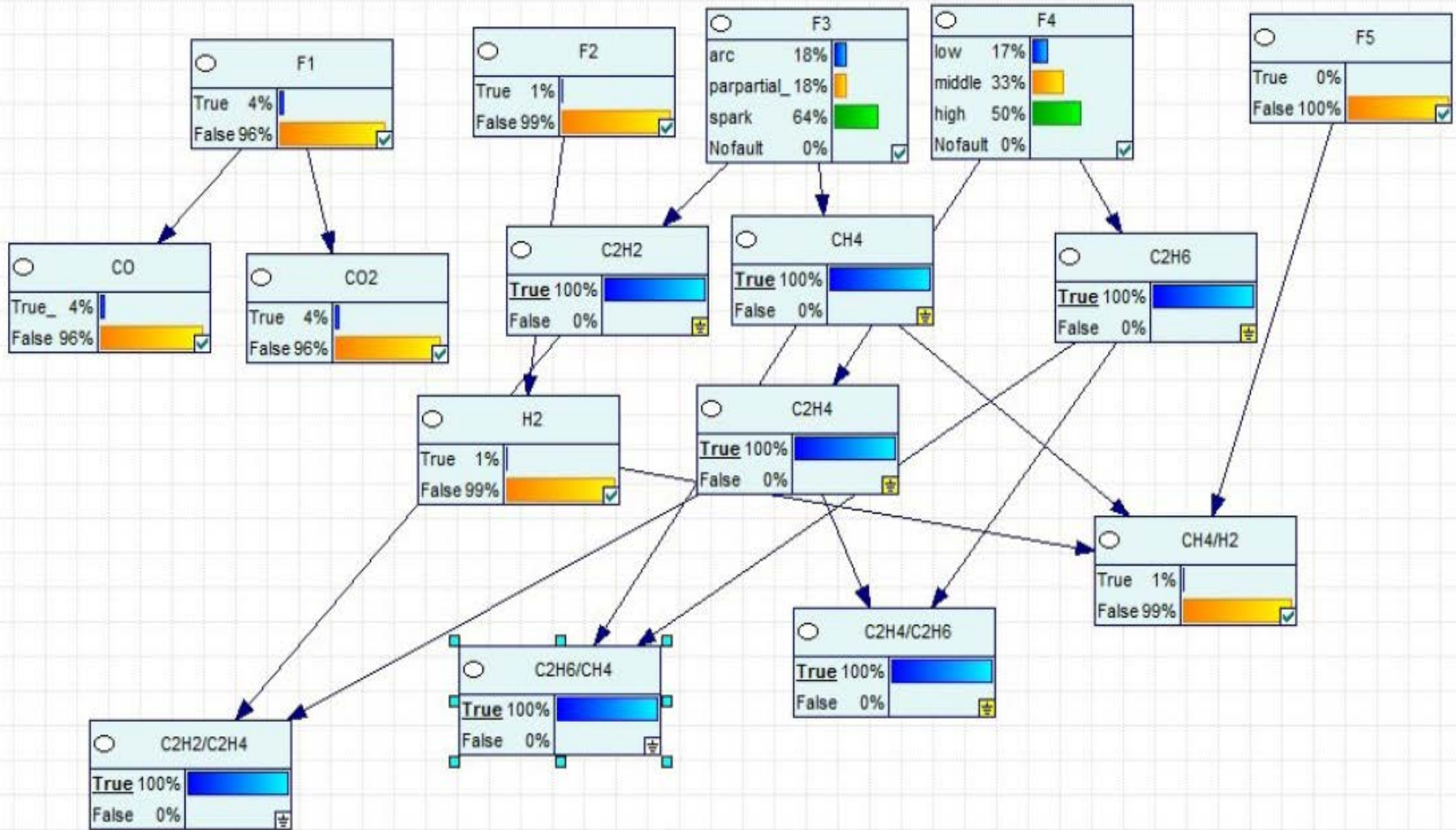
Agenda

- Introduction
- Transformer fault diagnosis
  - Motivation
  - Problem formulation
- Construction of Bayesian network
  - Definition and advantage
  - What ingredient
- Model development and case study
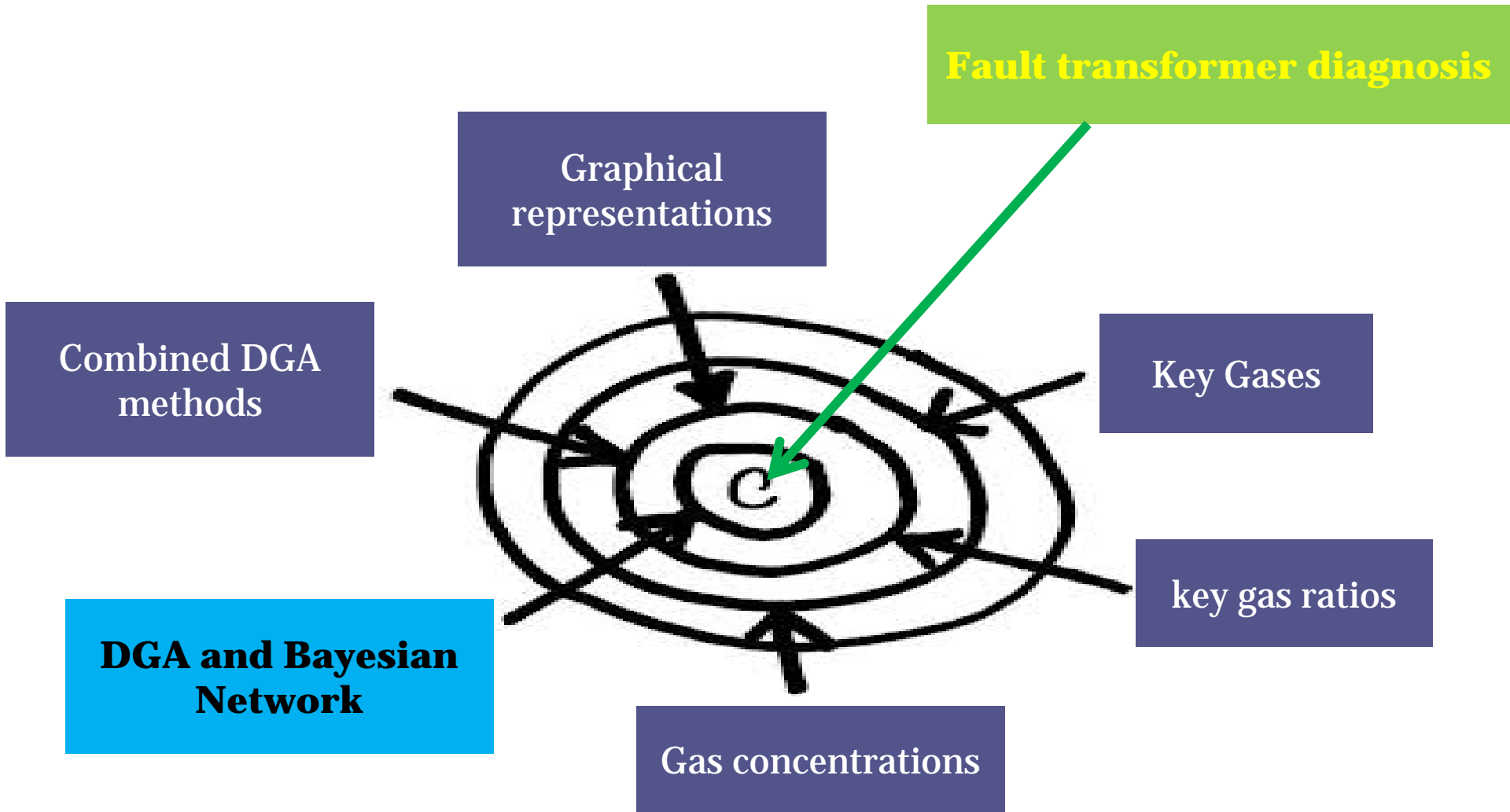- **conclusion and futur work**

Conclusion

The probabilities given by the Bayesian network show that the model presented in the studied case diagnose five faults including healthy state.

It supports various electrical and thermal severities.

Compared to Rogers Ratio Method which diagnoses only four faults in contrast, the developed model can diagnose all faults.

It is also possible to use all existing gas ratios in the same model.

Each method of DGA uses a number of ratios but the Bayesian model developed in this study supports all ratios of gas and key gases which is a great advantage.

Fault transformer diagnosis

Graphical representations

Key Gases

Combined DGA methods

key gas ratios

DGA and Bayesian Network

Gas concentrations

Future work

Our future work will be focused on a new contribution concerning transformer faults diagnosis by multi information fusion based on operating information and Dissolved Gas Analysis

Thank you for your attention