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Application of Artificial Intelligence for performance enhancement of Electrostatic Precipitator (ESP)

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Abstract

Electrostatic precipitators (ESP) are widely used to capture fly ash generated due to combustion of coal in thermal power plants. The basic principle used for fly ash collection is electrical charging of ash particle and subsequent collection and removal of ash from ESP. ESP performance is very dynamic in nature and is primarily affected by fly ash characteristics – e.g. resistivity or chemical composition, ash content in coal, ESP inlet temperature, moisture content in flue gas, condition of ESP internals, functioning of Rapping mechanism, presence of back corona etc. Presence of one or multiple reasons may severely affect ESP performance and may also lead to higher energy consumption with deterioration in ESP collection efficiency and sometime results in exceeding the prescribed emission norms. All the changes mentioned above in ESP behaviour are reflected in Voltage (V)-Current (I) characteristics. Due to dynamic nature, Human intervention is regularly required for ESP performance optimization to keep it at optimum point. This paper explains use of Artificial intelligence to replicate human knowledge to optimize ESP performance and identifying the probable causes for many ESP related problems.

Keywords: ESP, Artificial Intelligence, V-I characteristics, flyash

1.0 INTRODUCTION

Electrostatic Precipitators are widely used in Power plants, Captive power plants & Cement

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industry etc to capture particulate matter from flue gas generated due to coal combustion.
Particulate matter from industries is regulated through statutory limits notified by Ministry of Environment & Forest (MoEF). Particulate matter has remained a critical pollutant due to its health hazard to human. Recently MoEF has revised Emission limits[1] as per table below. Thermal Power Plants (units) shall meet the limits within two years from date of publication of this notification

Table 1 : PM Standards (in mg/nm3) as per Notification dated 07-12-2015

	Particulate Matter
Current Standards	150-350
New Standards	
Unit Installed till 2003	100
Unit Installed between 2004 and 2016	50
Unit installed after Jan 2017	30

To monitor compliance to above parameter in addition to other notified parameters, Central Pollution Control Board (CPCB) has published a directive titled "Protocol for real Time (Emission & Effluent) Data Management from industries Version 1.2(10.6.2015)[2]. As per the protocol, data from on line measurement system of Particulate matter is to be linked to CPCB and State Pollution Control Boards and excursion from the limit specified needs to be addressed by industry promptly to avoid action from regulatory agency as per the provisions of Environment Protection Act 1986. Data monitoring for excursion of the above parameter is being done based on Exceptions generated from supervisory software installed at CPCB. Alerts are generated automatically and sent to designated persons.
Electrostatic precipitators (ESPs) are widely used to arrest particulate emission from thermal power plant (fig 1). The basic principle used for fly ash collection is electrical charging of ash particle and subsequent collection and removal of ash from ESP. Modern ESP consists of number of fields (4-10) in a pass in series and are powered by separate energisation system for each field.

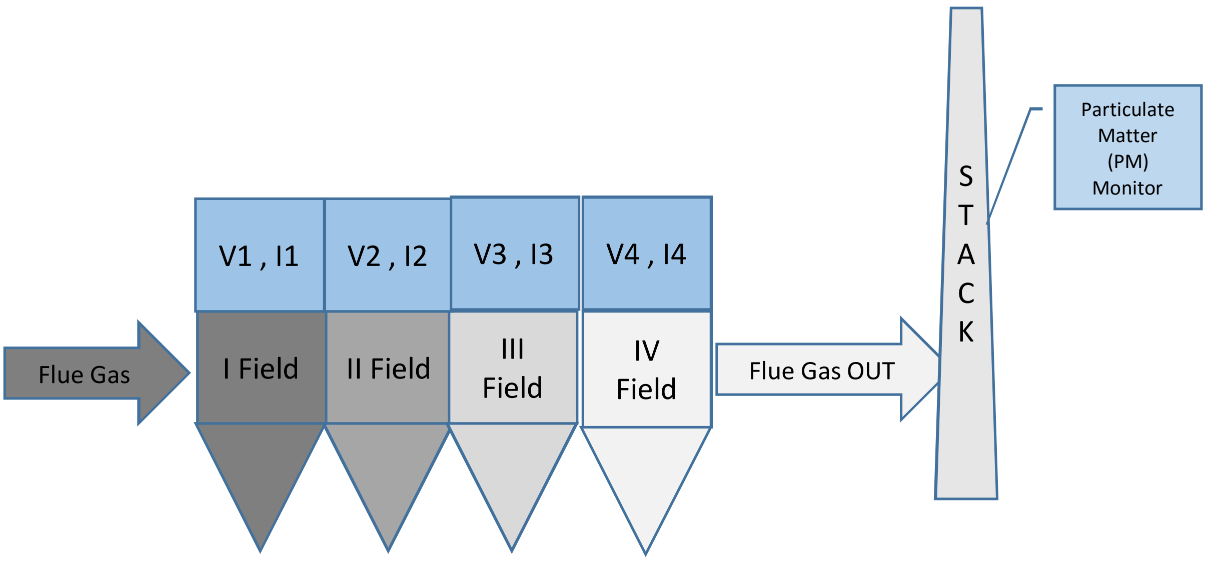


Fig. 1 – ESP Configuration in Thermal Power Plant

Performance of an ESP is reflected in Voltage and Current (V-I) relationship of a field individually and relative value of V-I among the fields in one pass[3,4]. The operational curves under operating conditions indicates as the gas passes through inlet field to outlet field, concentration of fly ash particles decreases and current increases significantly. This effect is depicted in figure 2.

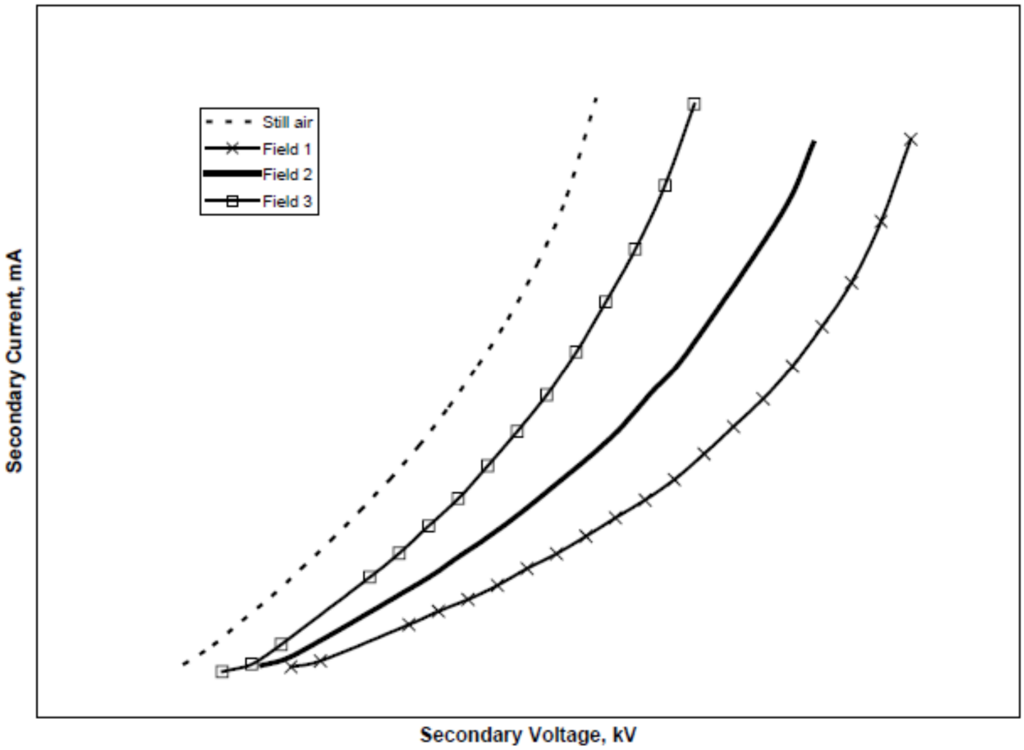


Fig 2 – V-I Curve for different fields [5]

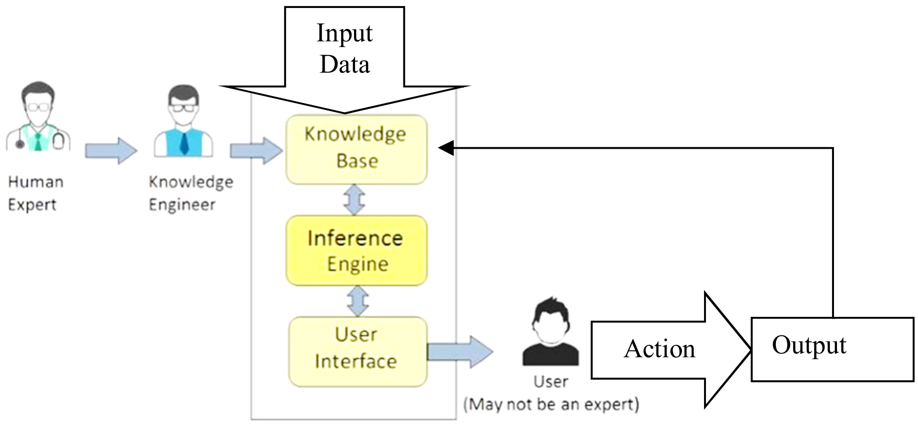
Since power plants are run continuously, performance of ESP is to be supervised continuously. Electronic controller is used to control V-I of individual field and charge management system[6]. Few modern electronic controllers have been incorporated with advanced software still manual intervention is required to optimize ESP performance due to dynamic nature of fly ash characteristics – e.g. resistivity or chemical composition, ash content in coal, ESP inlet temperature, moisture content in flue gas, condition of ESP internals, functioning of Rapping mechanism, presence of back corona etc. Presence of one or multiple reasons may severely affect ESP performance and may also lead to higher energy consumption with deterioration in ESP collection efficiency and sometime results in exceeding the prescribed emission norms. New advanced controllers are capable of deciphering voltage and current relationship of ESP and adjust controls to nullify adverse effect of changes based on algorithm in precipitation process to meet statutory obligation. However not all the changes can be captured automatically and human intervention on regular basis is required to keep ESP in healthy condition. Artificial Intelligence can be effectively used in application where human knowledge intervention is required on regular basis[7]. Artificial intelligence based Expert system can be used for ESP optimization. Here ESP of 4 fields in series has been considered to optimize. A suggestive algorithm has been simulated to provide a corrective action by adjudging V-I values and Output of Particulate Matter Monitor.

2.0 Artificial Intelligence based Expert System for performance optimization

An expert system for optimization of ESP performance can be developed that emulates and acts with the decision making capabilities of human being. Expert knowledge is imparted to expert system. Variation in output of ESP is generally due to following environment.

I. Variation in Inlet Dust Loading
II. Variation in Coal /Ash characteristics
III. Mechanical System Issues such as electrode misalignment, ash deposit & rapping system issues etc.
IV. Electrical Energisation Issues

Here it has been considered that Electrical system are in healthy condition.



PEAS Analysis for development of Expert system (Performance, Environment, Actuators & Sensors) is as below.

Agent Type	Performance Measure	Environment	Actuators	Sensors
Performance Enhancement of ESP	Particulate Matter < 50 mg/nm3, V1,V2,V3 & V4 > 30 Kv I1<I2<I3<I4	Variation in Dust loading / Variation in Coal /ash Characteristics Mechanical System Issues	- Reduction of charge in ESP by varying Charge Ratio / Adjusting the Current Limit - Power Down Rapping for 10 min. - Internal Inspection for electrode misalignment, Ash deposit, Failure of Rapping system component	Voltage/Current V1 , I1 V2 , I2 V3 , I3 V4 , I4 Particulate Matter (measured value) I1LM, I2LM, I3LM & I4LM

3.0 Algorithm

The algorithm requires voltage values and current values of all the fields. For simplicity, four fields were assumed although the algorithm can be easily extended to more number of fields. First, it asks for value of opacity. If the value of opacity is above normal, the algorithm proceeds to optimization of the fields in successive order. First and second fields have similar process of optimization, so do the third and fourth.

The algorithm continuously checks if the voltage value of the field is greater than 30kV and less than 95% of the current limit for that field. Once this condition is achieved, the algorithm moves on to the optimization of the next field. In the process of optimization for field 1(and field 2), the possible actions are reducing current limit value by 25% or fix it to a value. The algorithm remembers the success rate of successive current limit reduction and based on this, it makes a decision to whether to reduce current limit in steps of 25% or straightway fix a value.

In the case of optimization of third and fourth fields, the algorithm keeps checking against the same condition as iterated earlier, except that the course of action changes this time. The algorithm predicts the value of current at the given voltage based on linear regression curves for the V-I relationship that are determined from standard data points. Deviation between the actual and predicted value is measured, and the course of action is decided based on the deviation as well as success rate of different methods implemented. The actions, between which the choice is made, are increase charge ratio and power down rapping. The algorithm remembers the success rate of the methods and depending on which method was more unsuccessful, appropriate course of action is taken.

For the implementation of this algorithm (Appendix- A), various software tools were used. The code was written in Python 3.5.2 and libraries used are Scikit-Learn, NumPy, PyMySQL. SQL was used for storing the data regarding the program runs and success rates as required by the algorithm, along with the data training set for linear regression curves. Python was chosen because it has large number of libraries through which it is easier to implement AI algorithms. Scikit-Learn and NumPy are used for generating the curves that predict the values for current when voltage value is given based on standard data. PyMySQL was used as interface between Python script and SQL.

4.0 Analysis & Result

It was tried to analyze ESP performance issues in one of the ESP. This ESP was configured as 2 pass and 4 field/pass. This ESP was due for annual maintenance shut down. Detailed analysis of ESP voltage and current data was performed and all fields were optimized. V-I values were fed to Algorithm. Action suggested by algorithm were tried and results are tabulated in Table -2. Power Down Rapping (PDR) was done to remove ash deposited in 5 fields (Table – 2). After doing Power down rapping normal voltage and current was restored in 5 fields with increase in Peak voltages also, thereby increasing the electric field strength in ESP. Improvement was observed in 3 more fields by increasing the charge ratio. In one field (Field 1 of Pass 2) not much improvement observed. In this fields, it was suspected that either reduced clearance between electrodes or rapping system issue was suspected. During overhauling this fields were inspected thoroughly. In field 1 of Pass 2, one shock pad was found missing and heavy dust deposit was observed leading to reduced clearances. After providing shock pad normal voltage and current was attained in this field.

Table 2 : Secondary Voltage & Current before and after performing optimization

Field	Before		Suggested Action	After		Further Action
	Ave. Voltage (Kv)	Ave. Current (mA)		Ave. Voltage (Kv)	Ave. Current (mA)	
Pass 1						
1	28	020	Increase Charge Ratio by 25%	38	177	NIL
2	28	130	Increase Charge Ratio by 25%	35	196	NIL
3	42	160	PDR	38	698	NIL
4	35	380	PDR	32	1367	NIL
Pass 2						
1	44	00	PDR	41	056	Internal Inspection
2	32	028	Increase Charge Ratio by 25%	33	197	NIL
3	38	110	PDR	36	554	NIL
4	41	230	PDR	33	1102	NIL

After overhauling and taking corrective measures, Field 1 (Pass 2) could be charged normally and following voltages and current levels were achieved.

Table 3: Secondary Voltage & Current after overhauling in field 1 (Pass2)

Field	After Overhauling	
	Ave. Voltage (Kv)	Ave. Current (mA)
Pass 2 field 1	41	210

5.0 Conclusion

Based on the results achieved by application of artificial intelligence for ESP performance optimisation, it can be inferred that this approach can be used successfully for optimization of ESP and will replicate human knowledge inputs with its own knowledge engine. In highly abnormal condition such as mechanical issues with ESP, an internal inspection is also suggested.

Further this algorithm may be expanded to optimize ESP with large number of fields and keep the history of optimization activities done.

References

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3. Electrostatic Precipitation by Sabert Oglesby,Jr. and Grady B. Nichols, Marcell Dekker Inc, New York.
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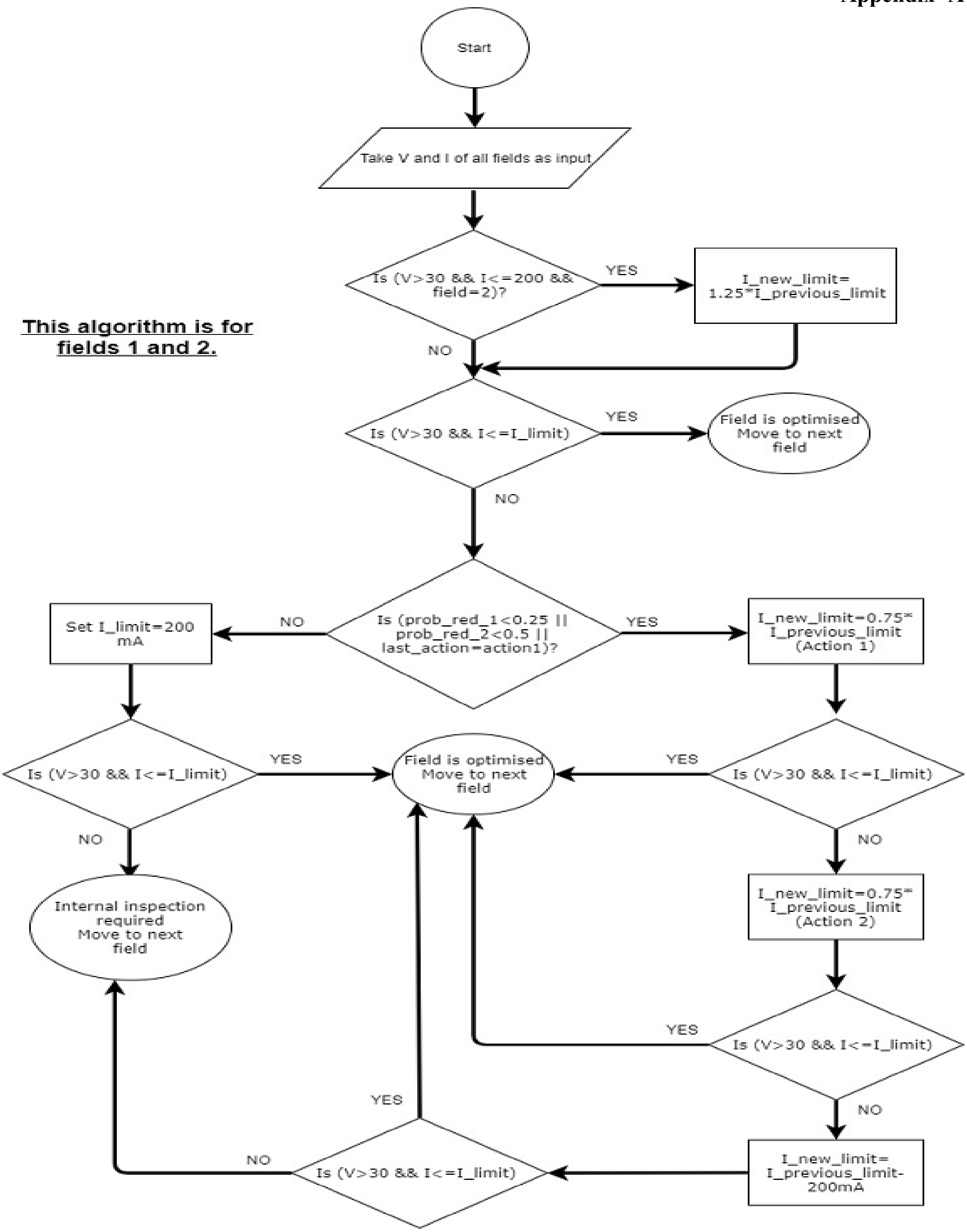
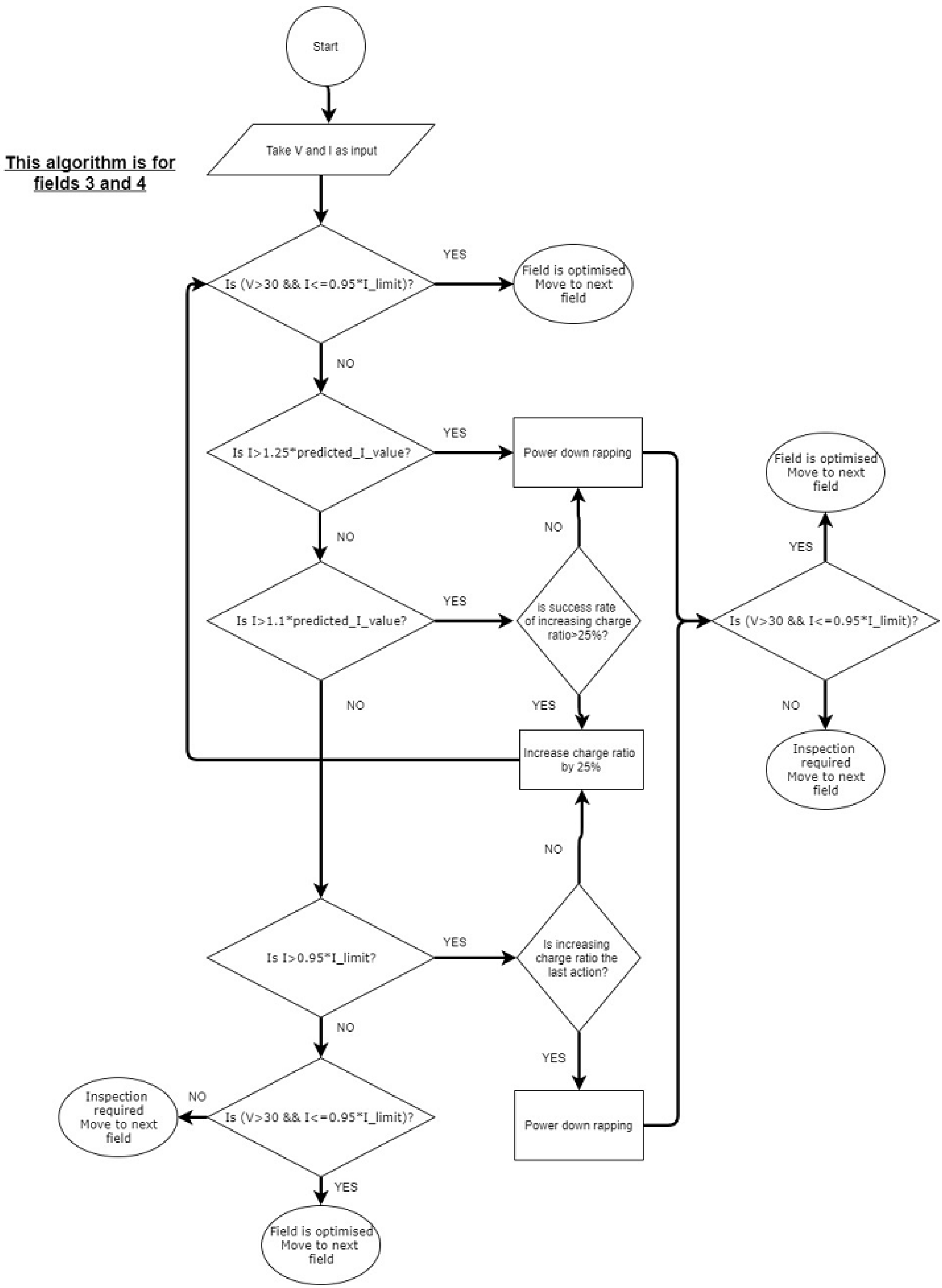
7. Artificial Intelligence A Modern Approach, Stuart J. Russell, Peter Norvig, Pearson India.

Appendix- A


Start
Take V and I of all fields as input
Is (V>30 && I<=200 && field=2)?
YES
I_new_limit= 1.25*I_previous_limit
NO
This algorithm is for fields 1 and 2.
Is (V>30 && I<=I_limit)
YES
Field is optimised Move to next field
NO
Is (prob_red_1<0.25 || prob_red_2<0.5 || last_action=action1)?
NO
Set I_limit=200 mA
YES
I_new_limit=0.75* I_previous_limit (Action 1)
Is (V>30 && I<=I_limit)
YES
Field is optimised Move to next field
YES
Is (V>30 && I<=I_limit)
NO
Internal inspection required Move to next field
NO
I_new_limit=0.75* I_previous_limit (Action 2)
YES
Is (V>30 && I<=I_limit)
NO
YES
NO
Is (V>30 && I<=I_limit)
I_new_limit= I_previous_limit- 200mA


This algorithm is for fields 3 and 4
Start
Take V and I as input
Is (V>30 && I<=0.95*I_limit)?
YES
Field is optimised Move to next field
NO
Is I>1.25*predicted_I_value?
YES
Power down rapping
NO
Is I>1.1*predicted_I_value?
YES
Is success rate of increasing charge ratio>25%?
NO
YES
Increase charge ratio by 25%
NO
Is I>0.95*I_limit?
YES
Is increasing charge ratio the last action?
NO
YES
Power down rapping
NO
Is (V>30 && I<=0.95*I_limit)?
NO
Inspection required Move to next field
YES
Field is optimised Move to next field
Is (V>30 && I<=0.95*I_limit)?
YES
Field is optimised Move to next field
NO
Inspection required Move to next field