Digital Protection of Power System
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Lecture 40
Application of AI-Based Techniques in Digital Protection

Hello friends. So, in this lecture, we will discuss about the Application of Artificial Intelligence-Based Techniques used in Digital Protection of power system network. So, the question comes, why to use AI based technique in protection area.

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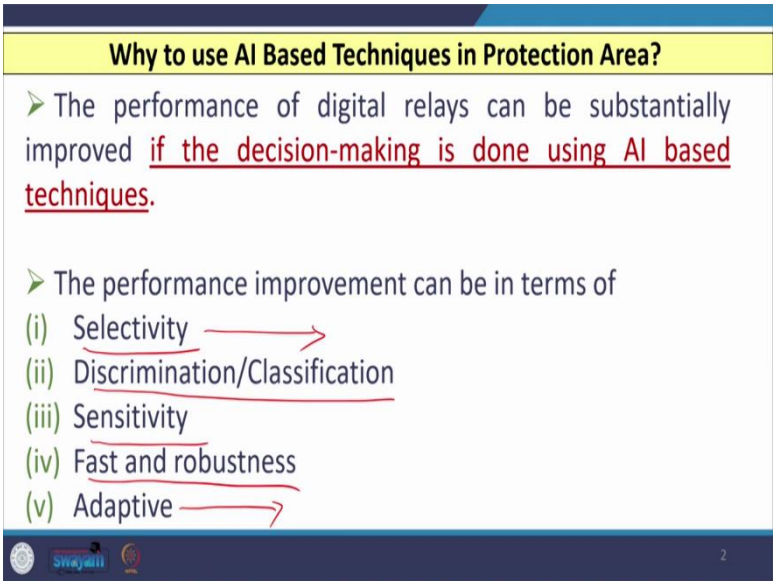

So, we know that the performance of digital relays can be substantially improved, if the decision making of those relays that can be done using AI based techniques. So, the performance improvement can be in terms of selectivity. So, if you use the AI based technique, then you can see that performance in terms of selectivity that can be improved and we can say that only faulty section that can be disconnected without affecting any healthy section.

The second advantage is the discrimination or classification. So, if I use AI based techniques for decision making in digital relays, then any event or fault that can be better discriminated compared to any other conventional techniques. So, classification or discrimination between internal fault and external fault or between in-zone fault and out of zone fault that can be done effectively, if we use AI based technique in digital relays for decision making.

The third is the sensitivity. So, if I used AI based technique in digital relays for decision making, then it improves sensitivity. So, definitely even though sometimes it may be possible that the magnitude of fault current is lower than the full load current of the feeder or the line.

So, that type of case is that can also be detected by such type of techniques, the response that becomes faster compared to the conventional techniques and if we wish to achieve or incorporate adaptive feature, then also we can easily incorporate wherever external system conditions changes, then whatever changes that is required in the settings of the relay that can be done adaptively if we use the AI based technique for decision making in digital relays.

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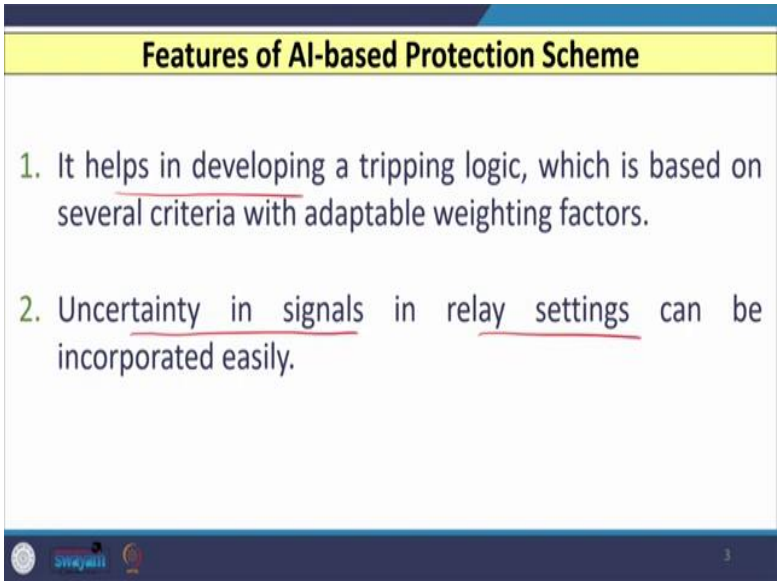

Now, let us see what are the features of AI base protection scheme. So, the first feature is that AI base protection scheme helps in developing a tripping logic in which we can have adaptive logic also using several factors which is known as weighting factors. Uncertainty if it is there in any signals which are acquired maybe voltage, current or any other signals and if those parameters are used in the calculation of relay settings, then that can be also easily incorporated using AI based protection schemes.

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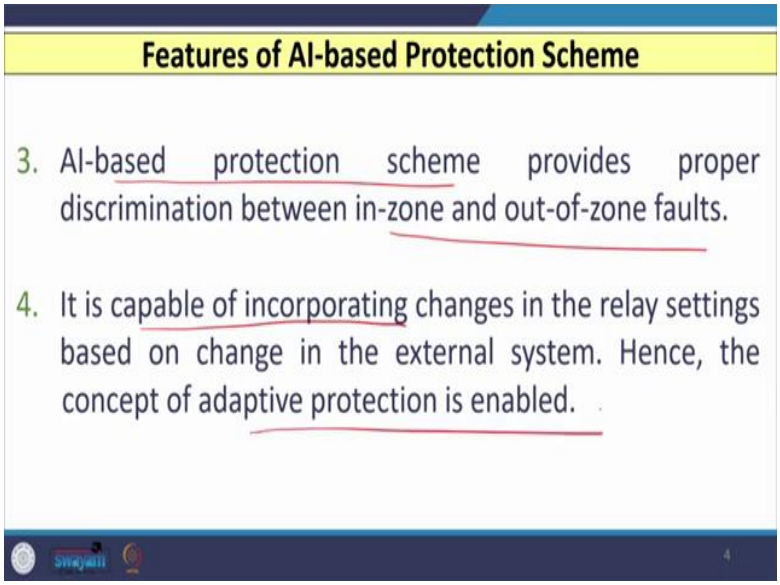

Further this scheme also provides proper discrimination between in-zone faults and out of zone faults. So, in case of in-zone faults relay operates whereas, in case of out of zone fault relay does not operate, it remains stable. Further utilization of this technique will also help in incorporating changes in relay setting based on changes in external system conditions. So, this type of concept is known as adaptive protection. So, such type of feature that can also be incorporated in the relay, if we use AI base protection schemes.

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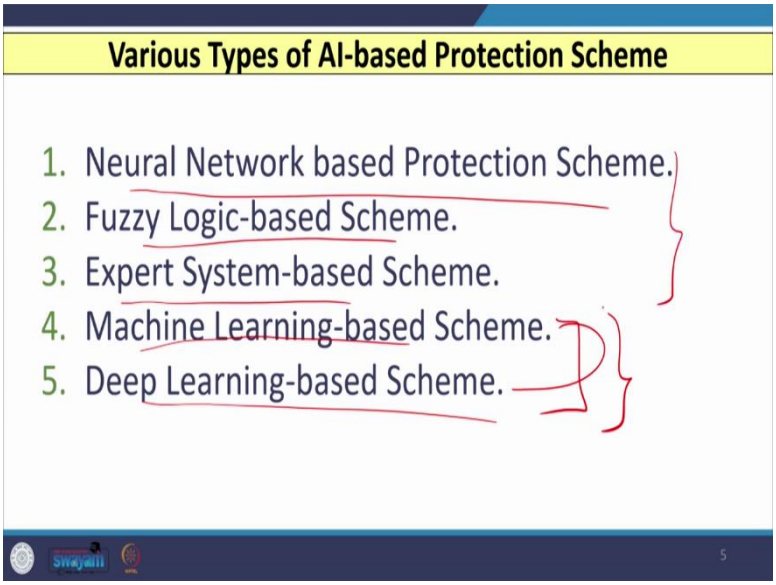

Now, let us see what are the various types of AI base protection schemes exist. So, there are mainly 5 types of AI base protection scheme exist the 1st is the neural network-based scheme, 2nd is the fuzzy logic-based scheme, 3rd is the expert system-based scheme, 4th is the machine

learning and 5th is the deep learning-based scheme. The 4th and 5th that is machine learning or deep learning-based scheme both are more or less same only the differences because deep learning is again the subset of machine learning.

So, we can say that this 2 categorize in the same category, whereas, the other 3 schemes they are different. So, let us discuss each scheme one by one. So, let us consider first the neural network-based scheme. So, if I consider the application of neural network-based scheme, then that can be easily applied for detection of fault classification of fault or maybe location of fault in transmission and distribution lines.

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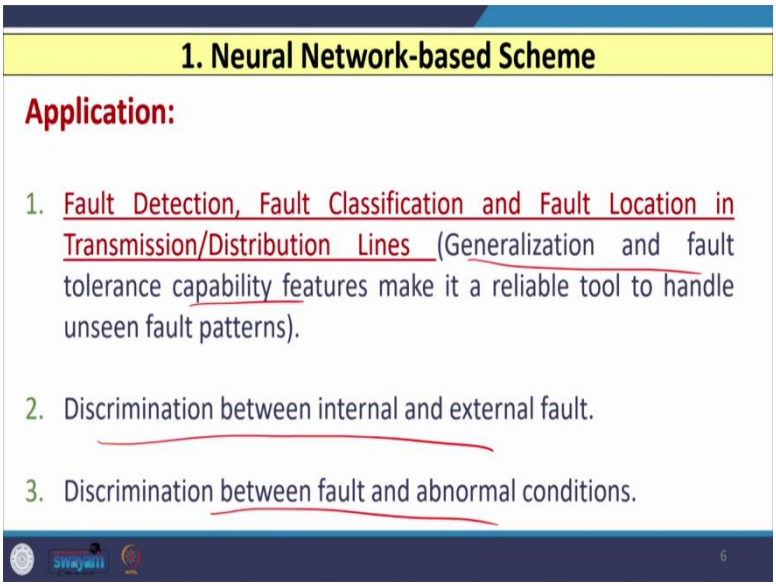

Why it is used? Because the neural network has a feature known as generalization and fault tolerant capability, because of that it can handle any unseen parameters. So, that that can be easily identified or classified. The second is discrimination between internal and external fault in that application also we can use neural network-based scheme and it can be also used when we wish to obtain the discrimination between fault and abnormal conditions.

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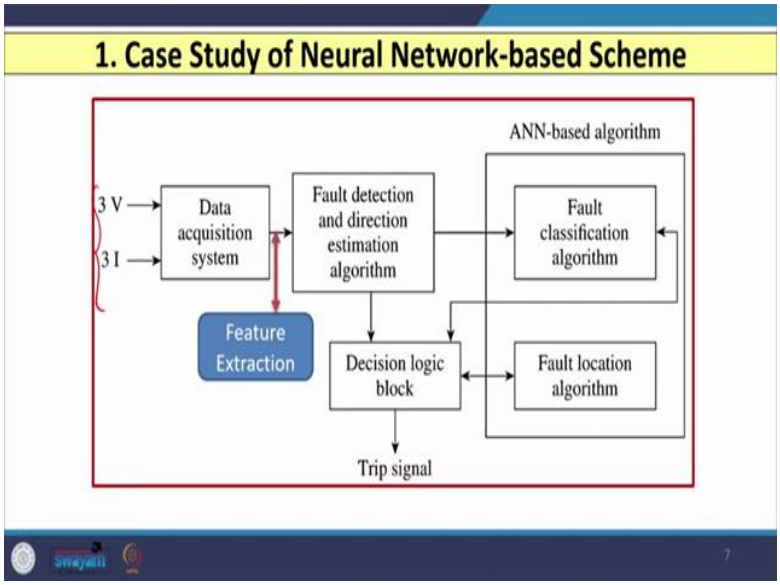

Now, let us consider one case study of neural network-based scheme. So, here you can see that the data are acquired by data acquisition system. So, we have continuous data we are acquiring the data let us say at 1 KHz or 2 KHz or 4 KHz sampling frequency. So, we acquire voltage or maybe current or maybe both data continuously we can go for a sliding window concept or moving window concept and then if required those data can be a feature also that means feature extractions can also be carried out because, whatever data we acquire. Let us say we acquire 3 voltage, 3 current and we do not require 3 voltage, 3 current we require only specific data, let us say 3 currents or maybe sequence components of voltage or currents or any other rate of change of sequence component or rate of change of voltage component. So, feature extraction plays an important role to capture only the useful features based on which the classification can be easily carried out.

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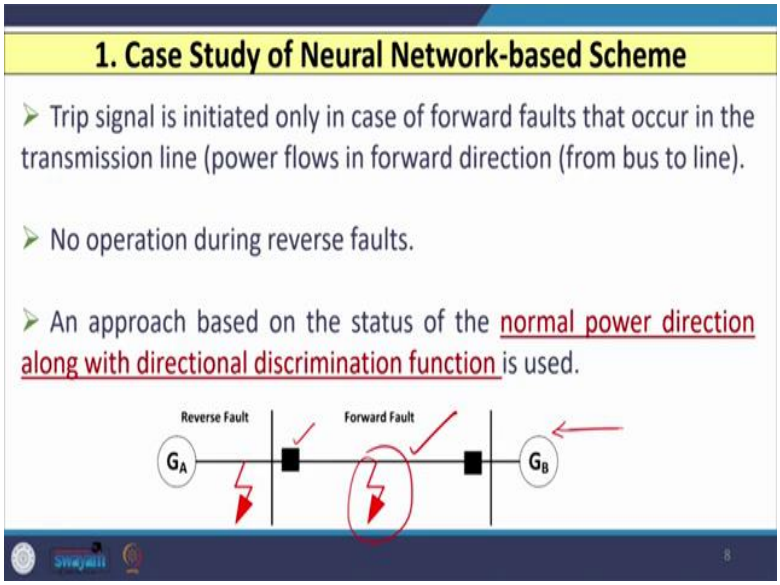

The next block is nothing but the fault detection and direction estimation algorithm. So, trip signal is initiated only in case of forward faults that occur on the transmission line. So, here you can see I have shown one single line diagram of a single terminal transmission line network where I have shown one fault that is termed as forward fault. So, any fault on behind this breaker that is known as reverse fault. So, tripping is only initiated in case of forward fault, there should not be any tripping in case of reverse fault and approach based on the status of normal power direction along with the directional discrimination function that can be used for directional estimation algorithm.

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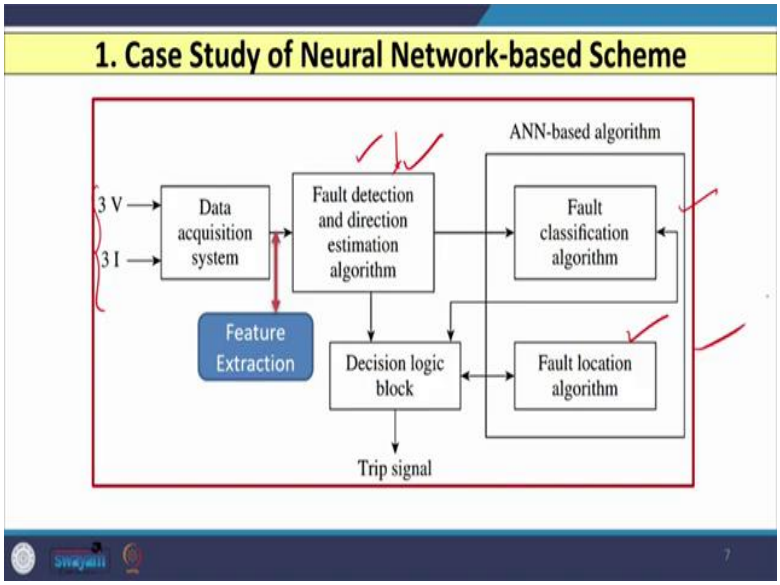

Once it is there means once it is confirmed that the fault is a forward fault, then we have to also simultaneously check that whether the fault is actually there or not or it is some abnormal condition. So, whether, actually the fault is there or no, if it is there, whether it is in forward direction or not that is confirmed by this block. Then after this the output of this block that is detection and directional estimation algorithm is given to the fault classification algorithm which is based on neural network and we have fault location algorithm also, which is also based on neural network. So, these 2 blocks perform simultaneously.

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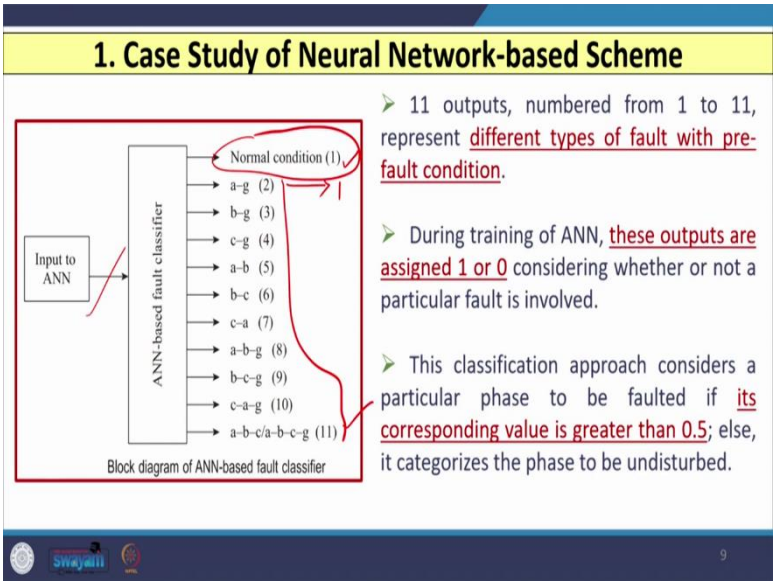

And if I consider the fault classifier block, let us say you have extracted the features and you are giving let us say 3 or 5 or 6 input to ANN for training and maybe after that testing purpose and then output of this classifier block which is based on neural network that is from 1 to 11 numbered and this represent different types of faults with pre-fault condition.

So, 1 indicates the normal or pre-fault condition whereas from 2 to 11 that indicates a specific type of fault. During training of neural network these outputs are assigned as number either 0 or 1. So, considering whether a particular fault is involved or not, you can have or you can classify the fault. For example, if you have the output, let us say at 2 number blocks, the output is 1 and let us say others are 0, then you can see that fault is a to ground fault.

And same way you can also classify some other types of faults. This classification approach considers a particular face to be faulted if its corresponding value is greater than 0.5. So, instead of taking directly 0 on one logic, you can also take if anything above 0.5, then that classifier

tells you that this is a particular type of fault which has occurred or if it is below 0.5 then that fault that is not classified.

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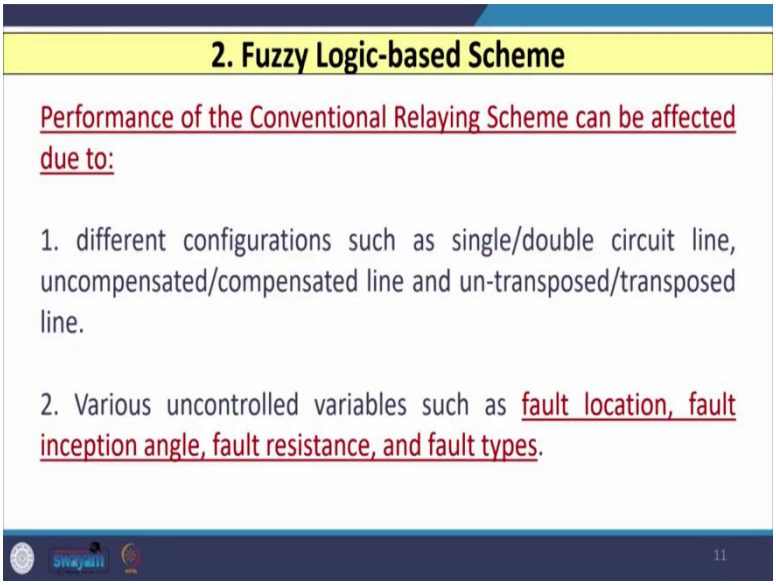

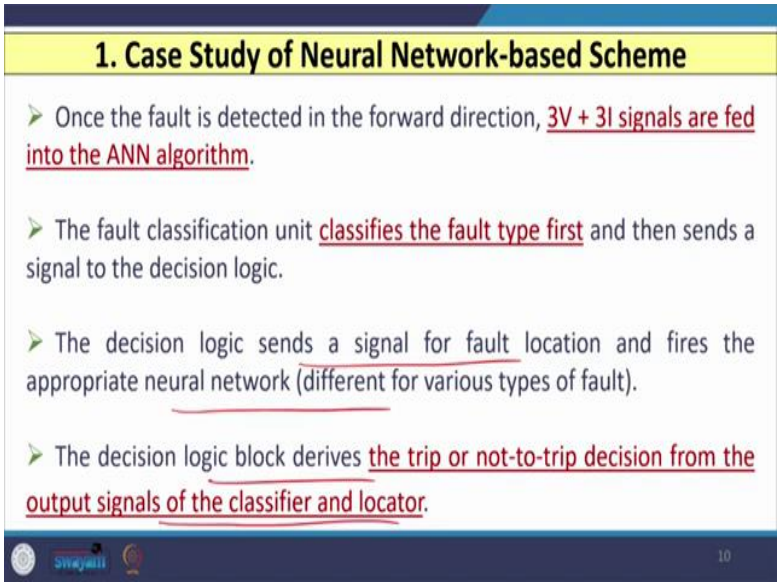

Once the fault is detected after that, let us say the performance of this classifier block that can be carried out or that can be assessed by generating some unseen patterns or events. And based on that accuracy of that classifier that can be obtained. The decision logic block sends a signal to the fault location and activates the appropriate neural network as I told you, which is different for different types of faults.

And finally, this block also derives the trip or no trip decision from the output signals of the classifier and locator which is finally initiated or given. So, that the operator that is easily aware that okay, this type of fault has occurred and at this much of fault location it has occurred. So,

then the maintenance can be carried out appropriately. Now, the second type of scheme that is known as fuzzy logic-based scheme.

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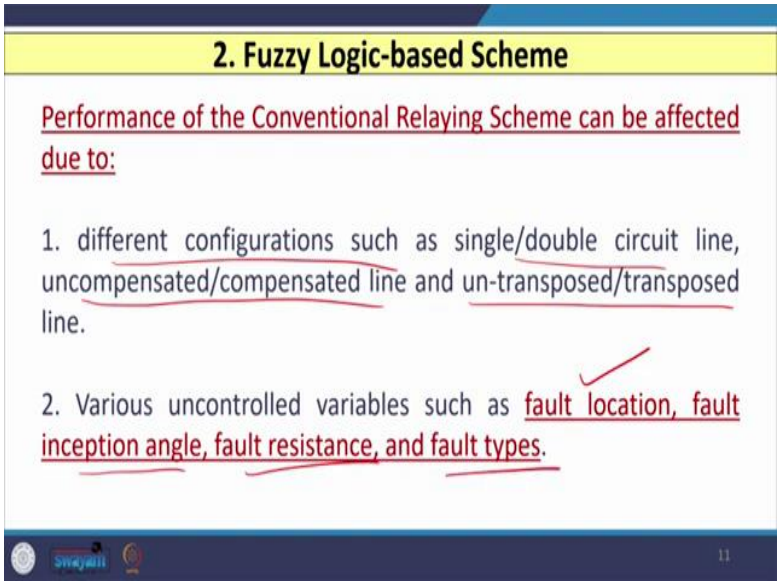

So, we know that performance of conventional relaying scheme that can be affected because of several parameters. For example, we have different configurations such as single or double circuit transmission line, we have uncompensated or compensated transmission lines, maybe series compensated and compensated and so on. We have un-transposed or transposed line.

So, because of that performance of the conventional relay that is affected, further, there are several uncontrolled parameters are also there like for location that is not in our hand, fault inception angle that is also not controllable fault resistance and fault type because of these factors, the performance of relay is affected badly.

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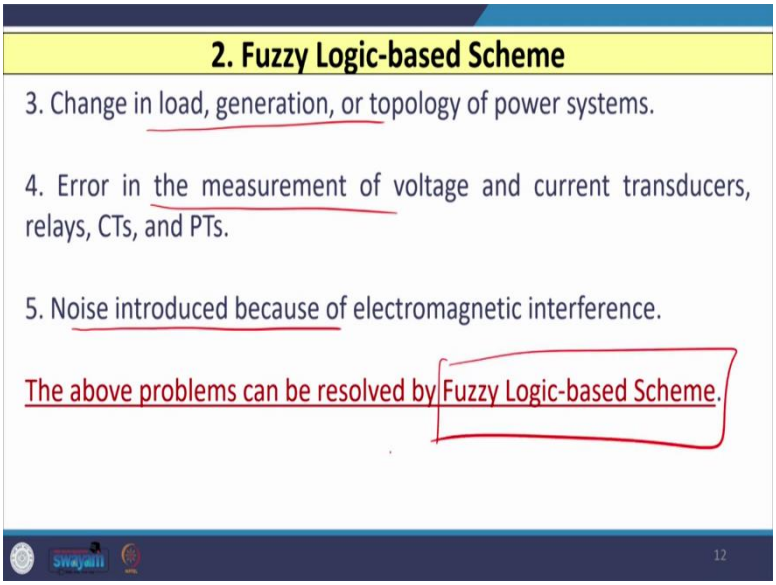

Change in load generation or topology of the power system that is also another factor, errors in the measurement of voltage and current transducers, maybe errors in the relays errors in the current transformers and potential transformers that also going to affect the accuracy of the relay and finally, the noise introduced because of the electromagnetic interferences that also we need to consider or take into the account. So, all these 5 problems that can be easily resolved if we go for fuzzy logic-based protection scheme.

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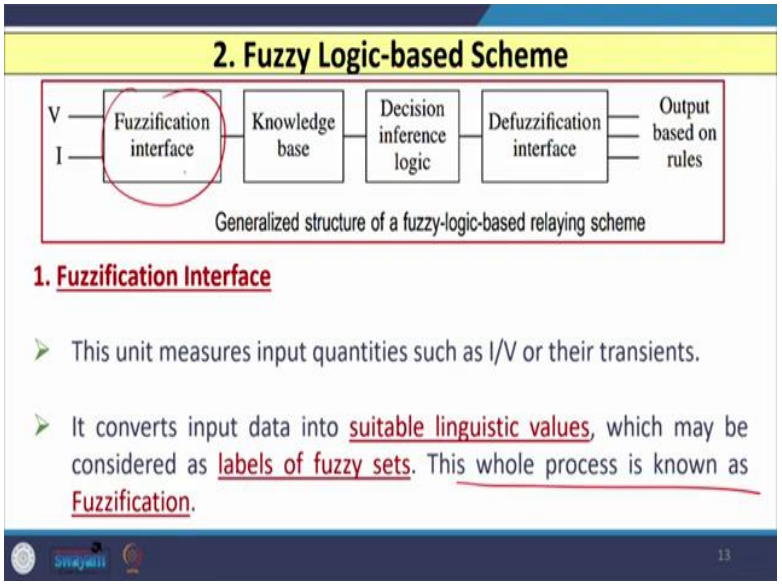

So, if I consider any fuzzy logic base protection scheme that can be applied to maybe for overcurrent or distance or for any other purpose, then it contains mainly 4 blocks, the first block is the fuzzification interface block. So, fuzzification interface block measures input quantities

such as current voltage or maybe their transients and it also converts input data into suitable linguistic values which may be considered as labels of fuzzy sets. And this whole process is also known as fuzzification process.

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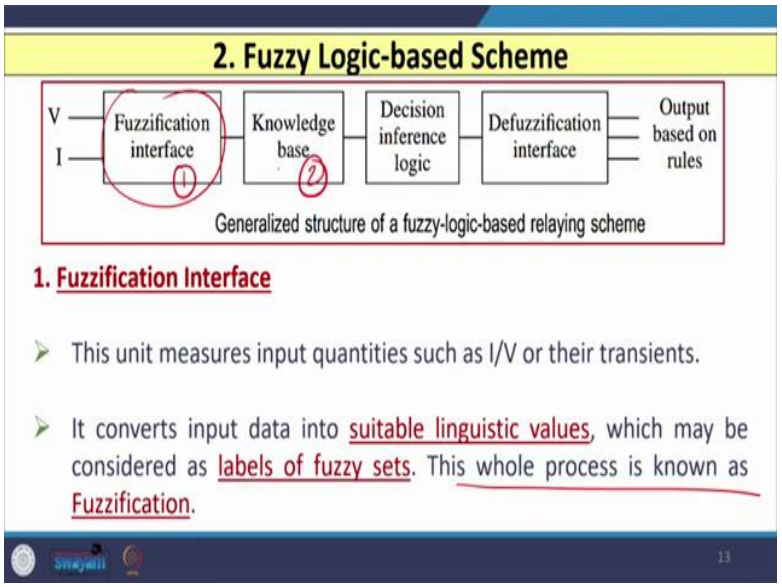

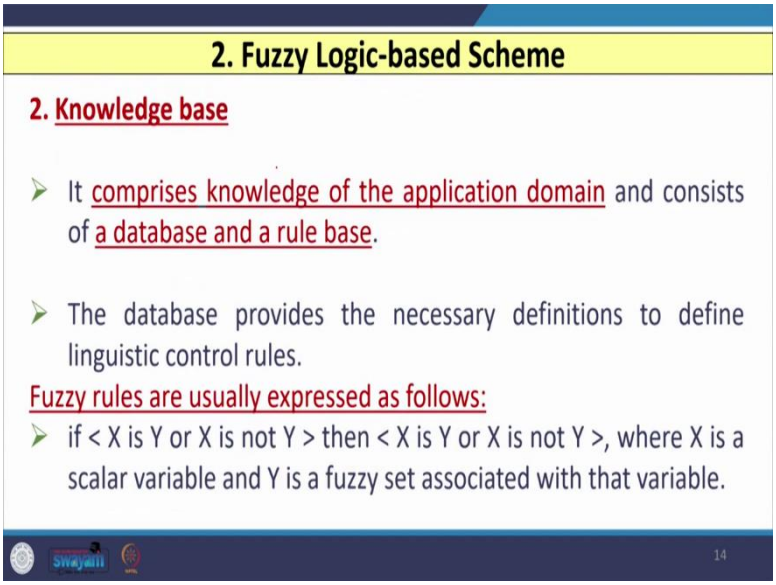

The second block that contains the knowledge base. So, knowledge base comprises knowledge of the application domain and consists of a database and a rule base. The database provides the necessary definitions to define linguistic control rules. For example, we have let us say rules like X is greater than Y, maybe X is less than Y, X is equal to Y. So, such type of rules we can easily form depending upon the requirement or application.

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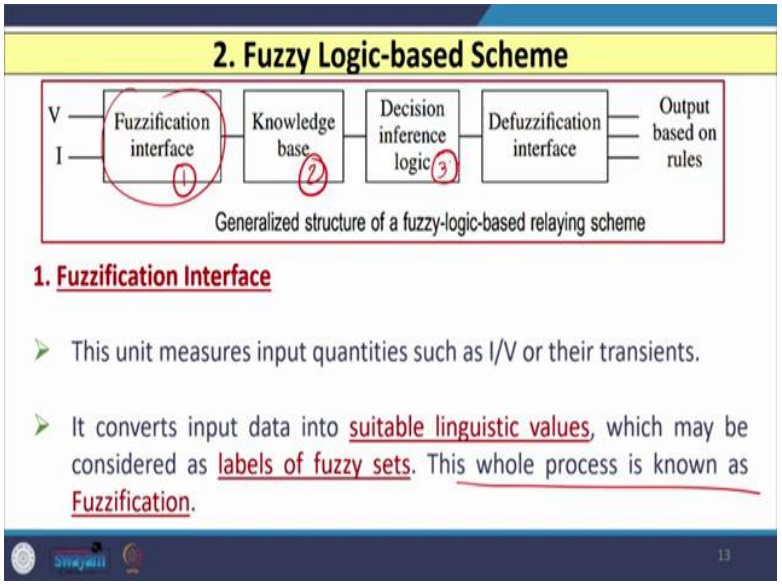

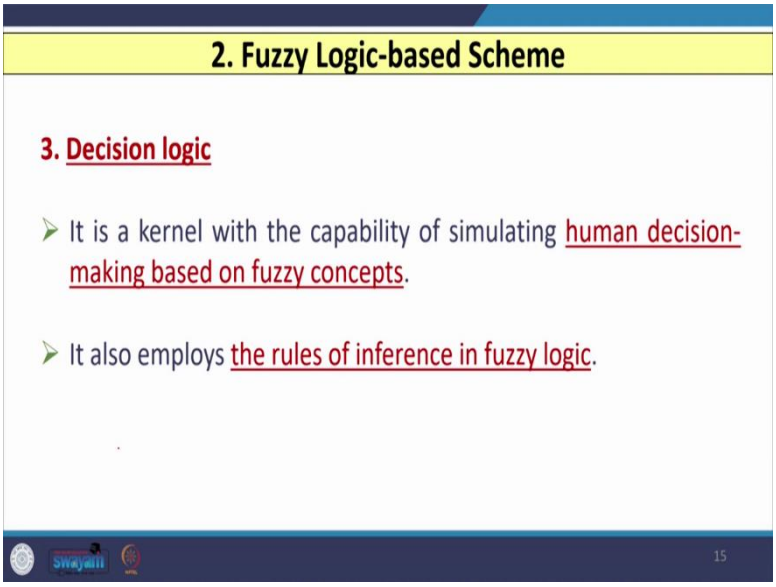

The third block that is known as the decision inference logic block. So, decision logic block is a kernel with the capability of simulating human decision making based on fuzzy concept and it also implies the rules of inference in fuzzy logic.

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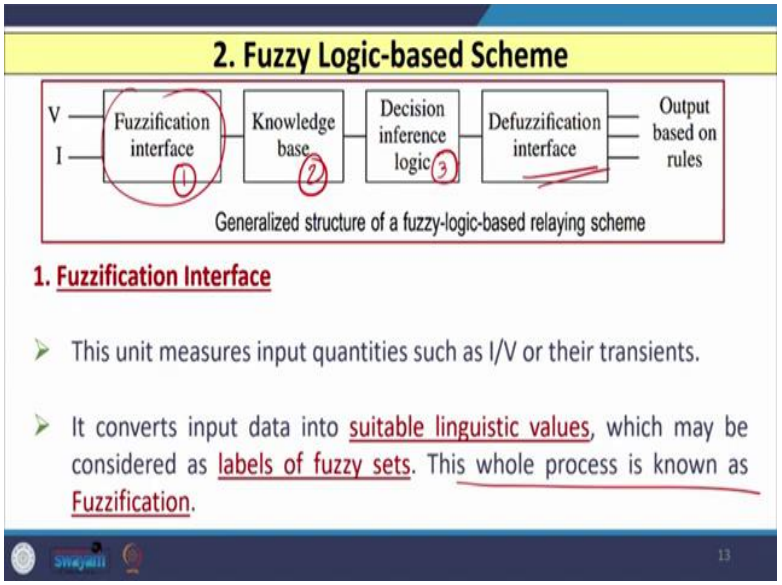

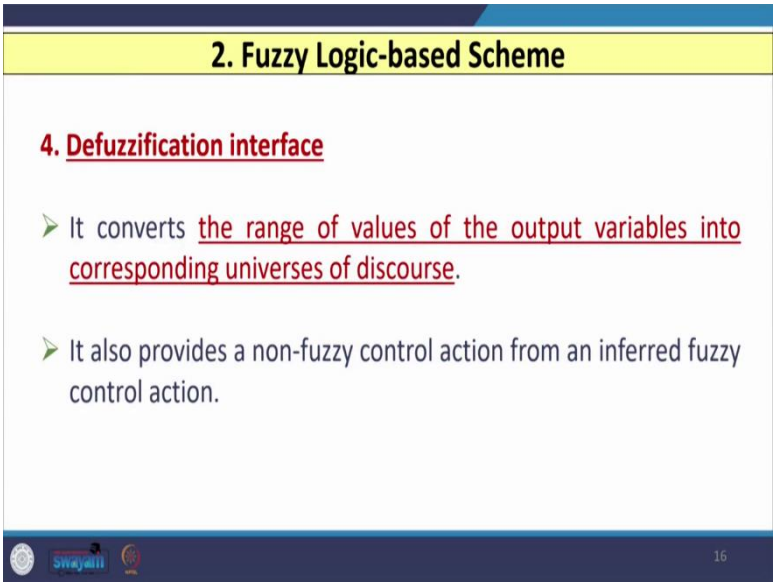

And the fourth block that is known as defuzzification interface. And in this block, it converts the range of values of the output variables into corresponding universes of discourse. It also provides a non-fuzzy control action from the inferred fuzzy control action.

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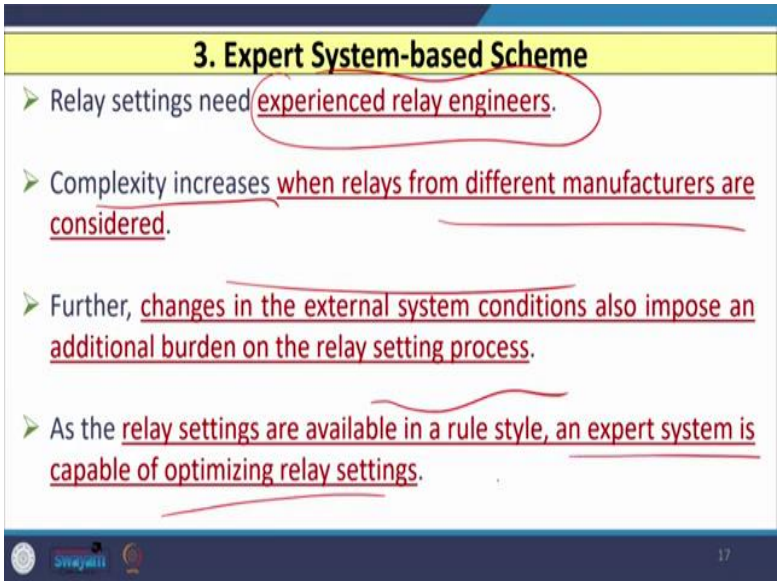

Now, let us consider the third type of scheme that is based on expert system. So, if we want to carry out settings of any digital relays or numerical relays or ID, then that need an experienced relay engineer. This complexity increases in terms of different relay settings when relays are again procured from different relay manufacturers, further changes in the external system conditions also imposes an additional burden on the relay setting calculations or processes. So, as the relay settings are available in a rule style, so, we can go for expert system-based protection scheme.

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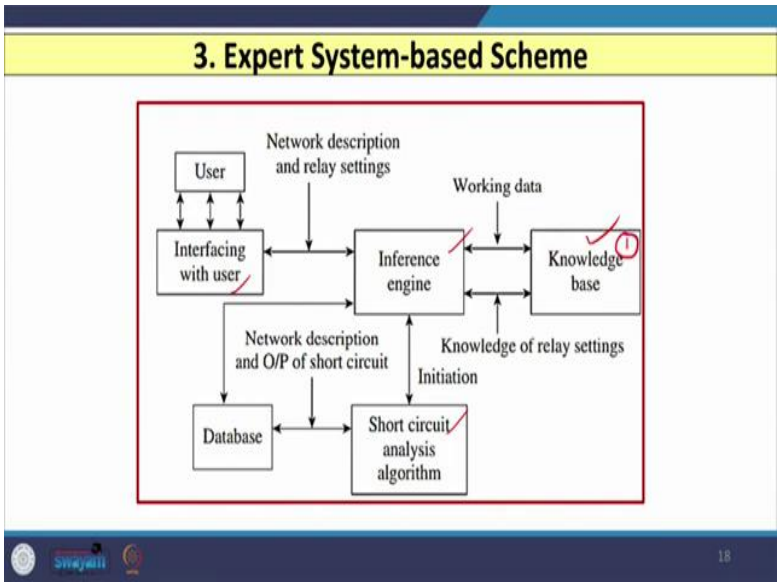

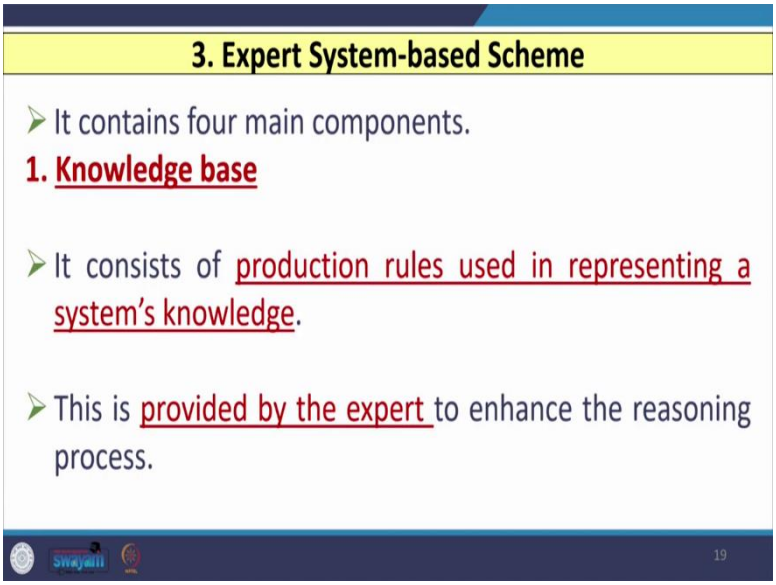

So, if I consider the block diagram of any expert system-based scheme, then you can see that that contains mainly the 4 blocks and these blocks are first is the knowledge base block. So, here this block is known as knowledge base block. So, this consists of production rules used in representing a systems knowledge this is provided by the expert to enhance the reasoning process.

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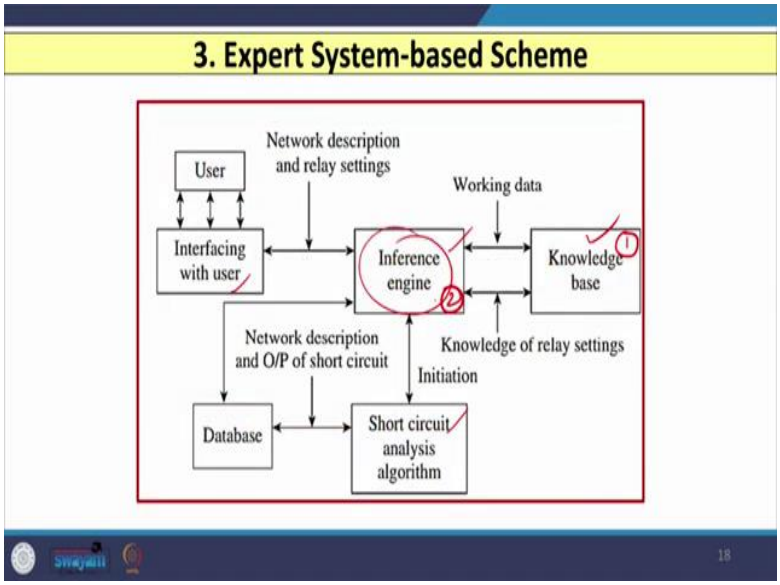

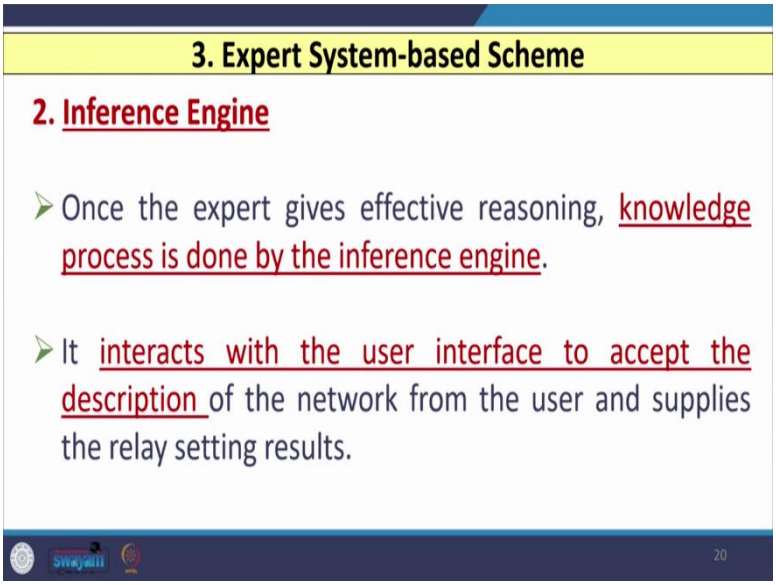

The second block that is known as the inference engine and if I consider this block then once the expert gives the effective reasoning, then knowledge process is done by this block it interacts with the user interface and accept the description of the network from the user and supplies the relay setting results.

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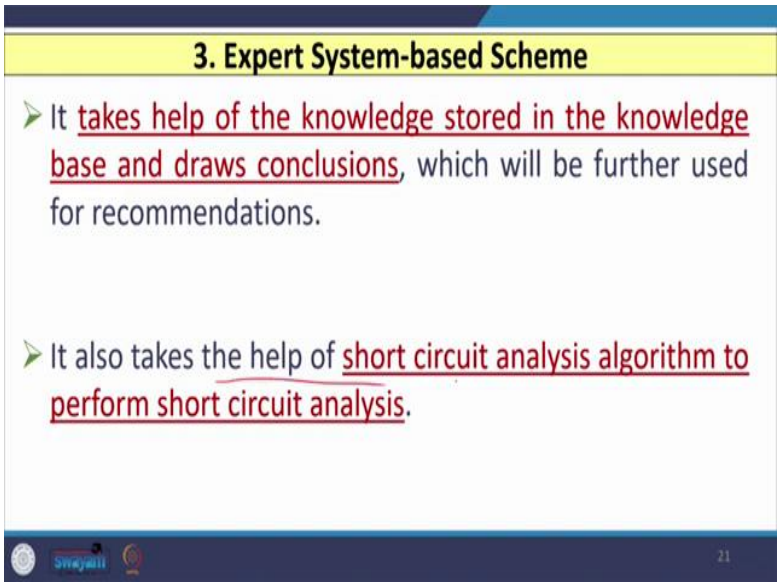

This type of block that is inference engine also takes helps of knowledge stored in knowledge base and draw some conclusions and such type of recommendations that is also passed to the other block. It also takes the help of short circuit analysis algorithm to perform short circuit analysis if it is required.

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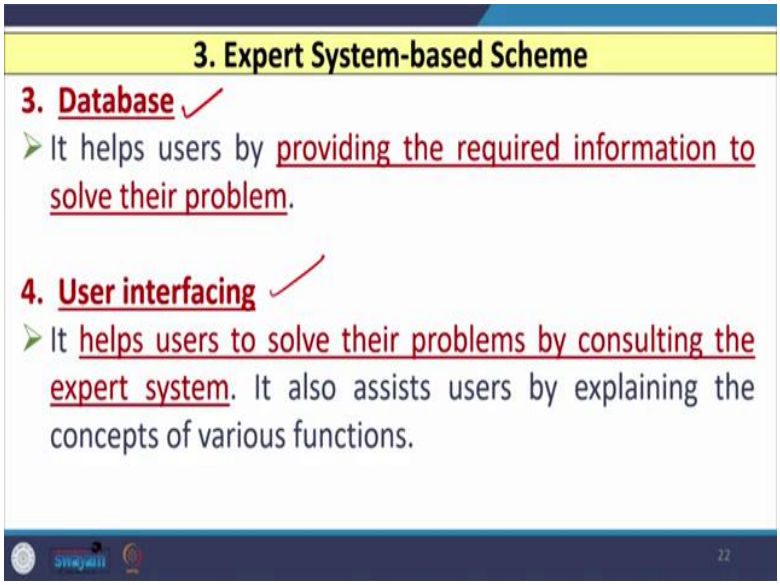

The third block that is known as the database block and it helps users by providing the required information to solve a particular problem. The fourth block is user interfacing block and it helps the users to solve their problems by consulting the expert system, it also assists users by explaining the concept of various functions.

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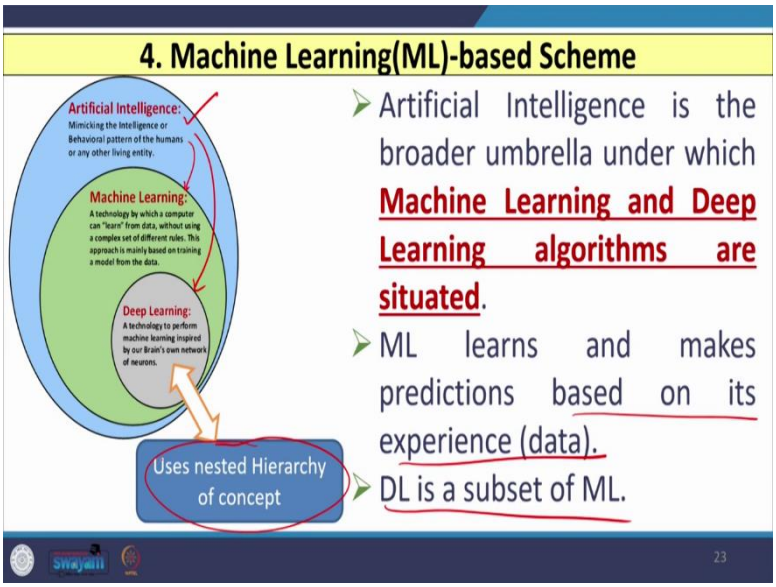

Now, let us consider the fourth scheme which is based on machine learning. So, we know that the artificial intelligence is a broader umbrella under which the machine learning or the deep learning algorithms are situated. So, you can see that for initially the artificial intelligence block is there under which the machine learning and the deep learning both will work.

Machine learning learns and makes predictions based on its experience or whatever past history or some data whereas, deep learning is also a subset of machine learning algorithms. So, deep learning used the concept of nested hierarchy and hence, it is more powerful than the machine learning and other techniques.

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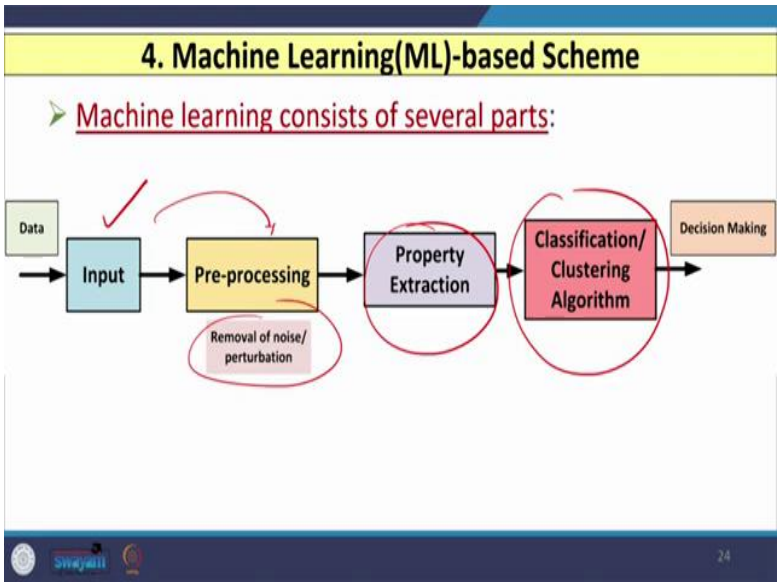

Now, let us consider what are the different parts involved in machine learning based scheme. So, whenever we consider a machine learning based scheme that needs some input, so, we have to take the input or we have to acquire some parameters, then the pre-processing that has to be carried out on acquired information or signals and this is required for the removal of noise then the property extraction is carried out. So, whatever features you need that features only you have to use for the decision logic and then based on that finally, classification, that is to be carried out by clustering or classification algorithm and final decision that is communicated.

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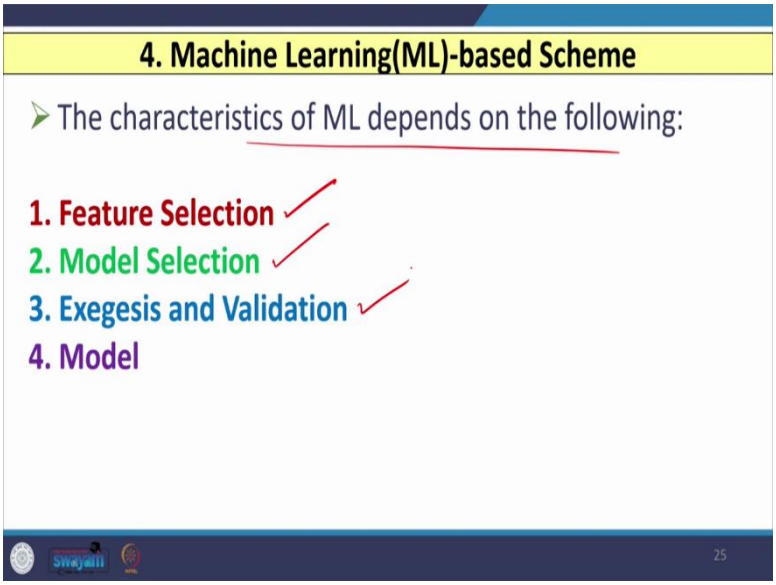

So, if I consider the machine learning based scheme, then the characteristic of this machine learning based scheme depends on 4 parameters. First is the feature selection, 2nd is the model selection, 3rd is the exegesis and validation and 4th is the model itself.

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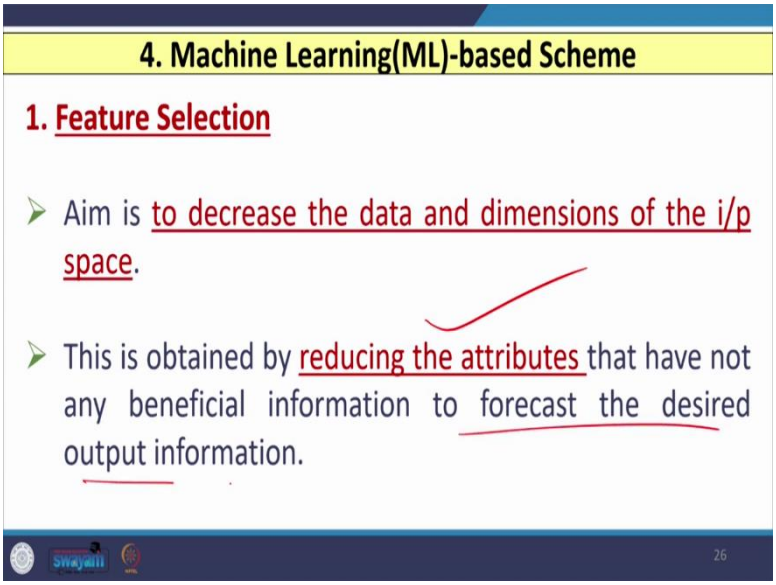

So, if I consider the first feature that is feature selection, then the aim of this is to decrease that data and dimensions of the input space. So, this is obtained by reducing the attributes that how not any beneficial information to forecast the desired output information.

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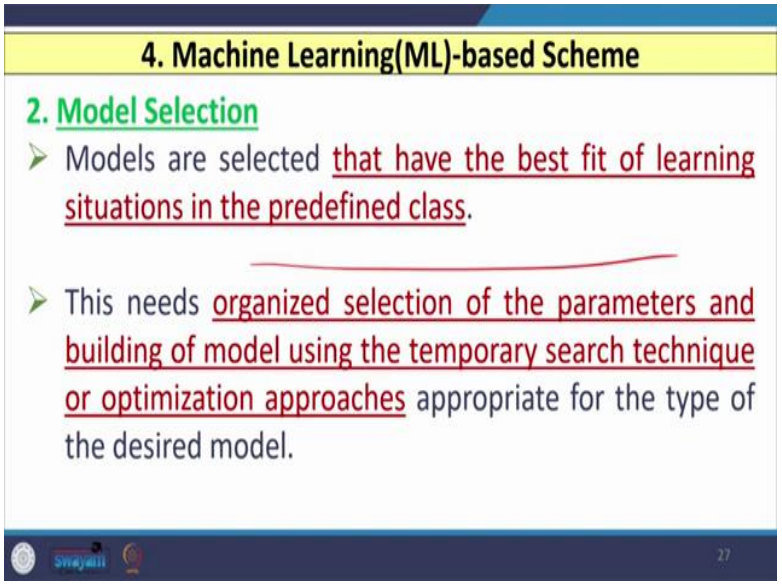

If I consider the model selection as another parameter, then this are selected that have the best fit of learning situations in the predefined class. These needs organized selection of the parameters and building of model using temporary search techniques or optimization approaches which are appropriate for the desired model.

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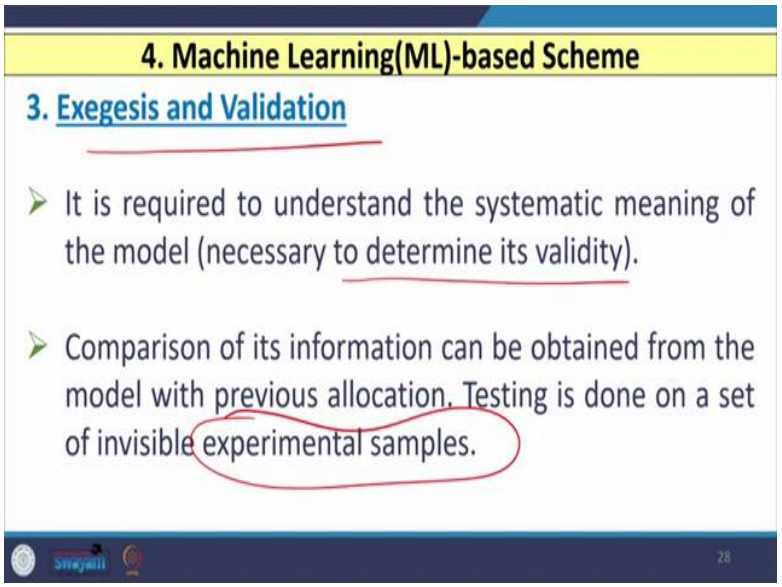

The third feature is the exegesis and validation. So, this is required to understand the systematic meaning of the model which is necessary to determine its validity, comparison of its information that can be obtained from the model with previous allocation or we can say past history and after that the testing is to be done on a set of invisible experimental samples. So, this is required or very important when we go for testing.

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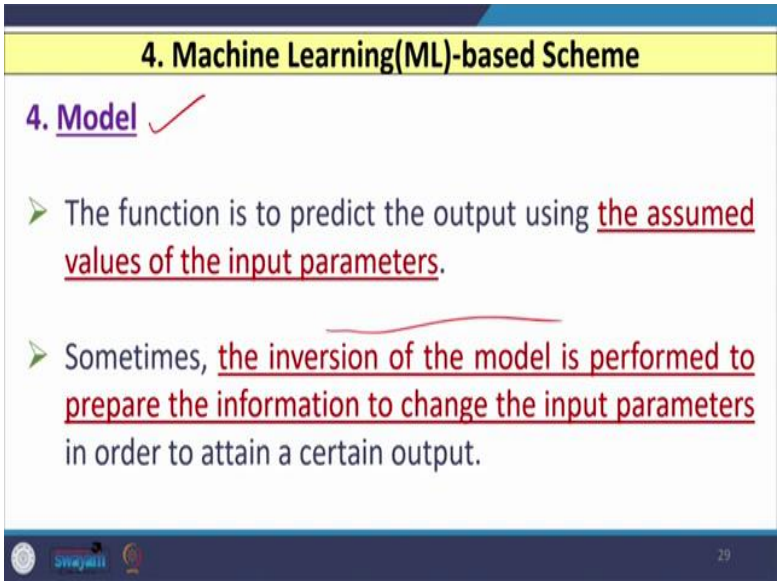

And the fourth feature that is the model itself. So, the function of this model is to predict the output using assumed values of input parameters and sometimes the inversion of the model is performed to prepare the information to change the input parameters in order to obtain a certain output.

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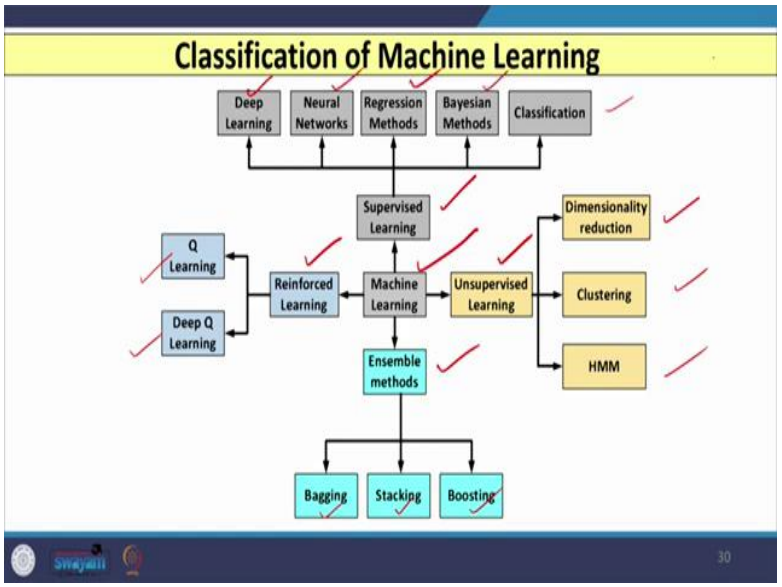

Now, based on this if I consider the classification of machine learning, then machine learning algorithm that can be classified as reinforcement learning. So, in that we have Q learning and deep Q learning are there. We have unsupervised learning in which dimensionality reduction, clustering and HMM are there. We have ensemble methods are there in which the bagging, the stacking and boosting are there and we have another supervised learning are also there, based

on which deep learning, neural networks, regression methods, bayesian methods and classifications are carried out.

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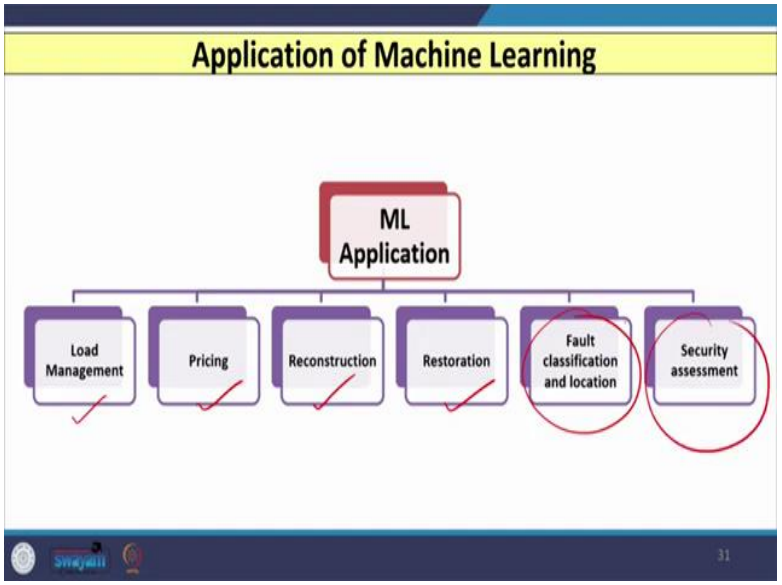

So, if I consider application of machine learning based schemes, then this type of schemes that can be applied for load management or maybe load forecasting also, it can be applied for electric pricing, it can be also applied for reconstruction of certain data or parameters, restoration also we can apply, we can also use this type of scheme for fault classification and location or better estimation of fault and then we can also use for security assessment.

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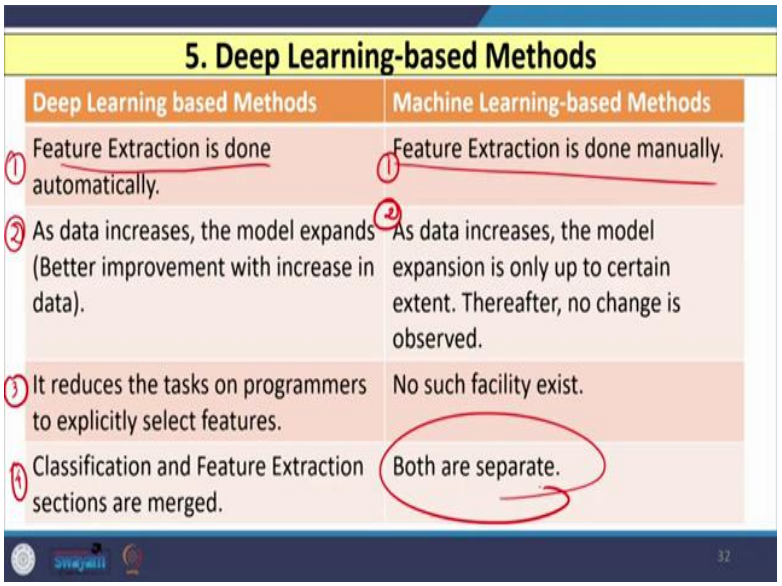

Now, the next method is the deep learning-based methods. Now, before we proceed further, let us discuss what is the fundamental difference between the deep learning-based methods and machine learning based methods. So, if I consider the deep learning-based method, then feature extraction is done automatically in deep learning-based methods, whereas, feature extraction is done manually in case of machine learning based methods.

Second is as the volume of the data increases, the model in deep learning expands and better improvement with increase in data that can be obtained. Whereas, in case of the machine learning based approaches, as data increases, the model expansion is only up to certain extent, thereafter, no change is observed.

The 3rd difference is the deep learning-based approaches reduces the task on programmers to explicitly select the features whereas, no such facility exists in case of machine learning based approaches. And 4th one is the classification and feature extraction sections are merged whereas, both are separate in case of machine learning based approaches.

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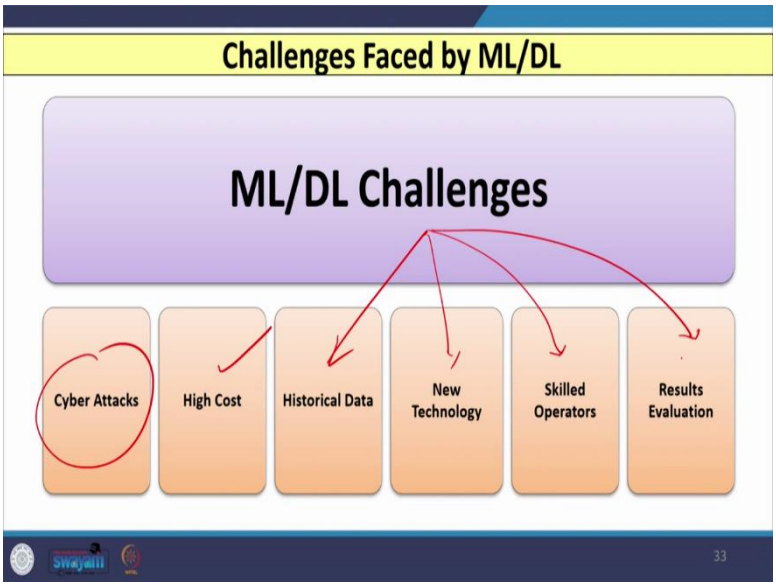

Now, let us see what are the challenges faced by machine learning or deep learning-based approaches. So, if I consider the first challenges that is related to the cyber-attacks, the second is the cost of such approaches that is very high, this type of approaches needs historical data, it is a new technology, we need skilled operators and after operating the results from such approaches proper evaluation of the results that has to be carried out. So, all these are the challenges of machine learning or deep learning-based approaches when it is used for protection of a particular devices or the transmission line.

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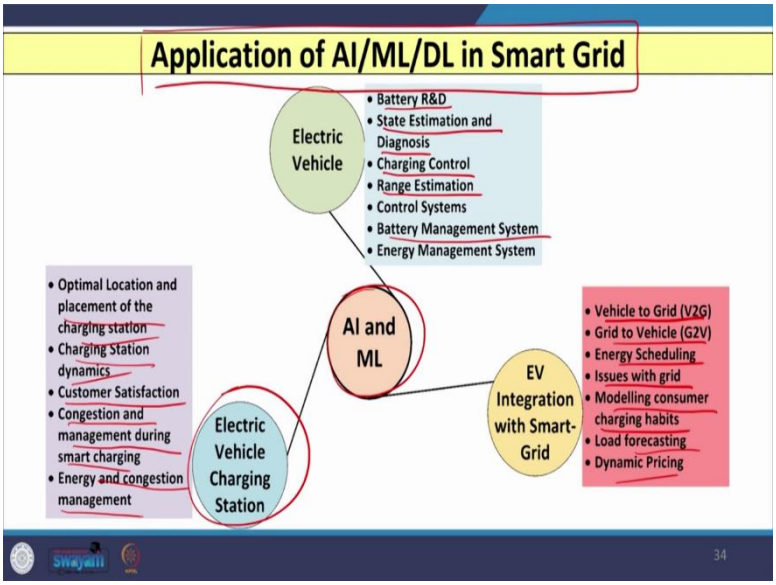

Now at last, let us see how we can apply AI machine learning or deep learning in a smart grid environment. So, the one example we can consider we know that the electric vehicles are increasing day by day and as we are shifting from the gasoline-based vehicles to the electric vehicles. So, the concept of AI, ML or deep learning that can be easily applied in this case. For example, if I consider AI, ML or deep learning, then it can be applied for electric vehicle applications where we need the research and development for battery of the electric vehicle.

For state estimation and diagnosis purpose we can go, we can use in charging control range estimation, maybe we can use it this thing in battery management system or energy management system of electric vehicles. If EV integration or electric vehicle integration is carried out with the smart grid, then we can use this AI, ML or deep learning in vehicle to grid mode, maybe grid to vehicle mode, maybe we can use for energy scheduling, we can also use to tackle issues with the grid, maybe modelling, consumer, charging habits, load forecasting and dynamic pricing in all such applications, we can use the concept of AI, ML or deep learning and we can design the method based on this.

The next is the application related to the charging station of electric vehicles. So, optimal location and placement of charging station that is also another area where we can use a AI, ML or DL we have charging station dynamics. Customer satisfaction is also there, congestion management during smart charging and energy and congestion management in all such applications, we can use the concept of or application of AI, ML or deep learning based methods or approaches and we can design the appropriate methods and one very important

thing is when we are dealing with electric vehicles in smart grid environment, then they need a huge data and handling of those data we have to go for either the AI, ML or deep learning based approaches.

So, in this lecture, we started our discussion with the what are the advantages of, application of AI, when it is used in decision making of the digital relays, then we have discussed the different types of approaches for we started with neural network-based approaches, then we have considered the fuzzy logic-based schemes and then we have considered the experts system-based schemes and then we have discussed the machine learning and finally, deep learning-based approaches.

After that we have discussed an application of AI, ML or deep learning-based approaches in smart grid environment particularly when the EV integration is carried out in smart grid along with certain other renewable energy sources. So, we know that this is the last lecture of this course. And I hope that you have enjoyed this course the different assignments that is given for each unit, and you will also carried out some exercises for each assignment. So, I hope you have enjoyed the course and I wish you all the best. Thank you.