# Overview of IED Hardware and Software in Power Systems

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**Speaker 1** 00:00

Okay, so we obviously will go through sample and hold, sample and hold. Each channel will have sample and hold, sample and hold, and we will, you know, hold the signal at exactly same time. So all four will come to a multiplexer, okay? And the role of the multiplexer is to select one at a time and apply to A to D converter, okay? So sometimes if we want to save on A to B converter, we will use the multiplexer. And multiplexer is nothing but a simple switch, okay? It will first switch on this signal and that will be converted then, then it will switch the second, third and fifth. So obviously your total conversion time will obviously increase. Total data acquisition time will increase because you are not acquiring, converting all of them in value.

**Speaker 2** 01:06

Okay?

**Speaker 1** 01:07

So this is where you will use a multiplexer. So it's a very simple circuit, okay.

**Speaker 2** 01:15

Where.

**Speaker 1** 01:17

So to transfer the sample value from sample and hold amplifier one by one. That's the main purpose of this, okay? It's basically a switch, a signal. And usually you get, you know, four to one multiplexes fairly cheap, you know, so you can apply four channels to one multiplexes. So basically, you know, from your microprocessor, this is your microprocessor here, this is the processor, okay? Because you are controlling everything from here. So you will actually control this at the multiplexer and also A to the converter from the processor. What you will do is if it is a four to one, you just need two bits, right? So using two bits you will either select this, this, this and that. And then once that is selected, then you will start your A to D converter and then get the value. Then you will do the next one, start your A to D converter and get the value.

**Speaker 2** 02:31

Okay?

**Speaker 1** 02:32

I'll show you the whole sequence of signals, how it works, okay? So you can have input signal either single handed or differential, okay? Most of the time it will be differential, okay? So that you don't mix up the grounds of all these together, right? And then you come to the, once the numbers, once you receive the data, you come through the process, okay? So digital processor, there are various types that are used, okay? There is nothing specifically designed for ieds, okay? They use, you know, existing processors that are used even in other areas. So general purpose microprocessors, they are used. There are single chip microcontrollers that are used, you know, for simpler functions. So microcontroller will have all these things built in into one chip with the processor.

**Speaker 2** 03:39

Okay.

**Speaker 1** 03:39

But obviously at a much lower level, you know, one a To D conversion, maybe it will allow only two channels, okay. Even sometimes just one channel. So depending on your requirement, you could use single chip microcontroller. There are a bunch of memory on it as well. So, you know, some limited functions will be there. But depending on your requirement, you could use it, you know, for service. And then there are DSP chips, okay. Which are mainly designed to implement filters, okay? And as we saw, or our algorithms are nothing but filters, okay? So you can actually very efficiently implement them on DSP chips. And majority of ieds actually will use more than one processor, okay? One processor may be just for computing, okay? That one will be, say DSP chip. There will be one processor that will be mainly for communication because now we will see later on communication has become big part of all these ieds.

**Speaker 1** 04:55

And there could be one processor that is just used for operator interface, okay? So depending again on the functionality of ied, they will definitely use more than one process, okay? Because one processor can't handle. Now what is happening next is cybersecurity, okay? Grant id's really have nothing built in for cyber security, okay? So the next level is to actually add that functionality. And that is very, very much computing intensive, okay? You need a special separate chips or separate processor just for implementing cyber security. If I have time, I will give you a very brief idea of what is happening in cyber security. It's a new area, okay? And it's extremely important. And one thing people get confused that cybersecurity is just like IT people do it. No, it's different in what we call operational technology.

**Speaker 2** 06:15

Okay?

**Speaker 1** 06:16

Yeah, but we call OT rather than it, okay? You need IT security in the office for sure, okay? But in the field for id's and for other computers, substation computers, you need OT security, which is completely different than IT security. So that's an area that's really coming up, let's say, you know, I'll give you some idea of that. Actually, I'm going to give a full course towards the end of the year.

**Speaker 2** 06:54

Not here, outside.

**Speaker 1** 06:56

They have invited me to give a course just on cybersecurity, especially for these kind of devices.

**Speaker 2** 07:03

Okay.

**Speaker 1** 07:04

There are some standards coming up, but there are gaps in those standards also. But I will try to give you a very brief idea based on the time we have, okay? But let's get back to this. So DSP chips, as I said, they are specially designed to implement the filters. So they can actually implement various types of functions. You know, fast Fourier FIR filters, that's the one we designed. And finite and pulse Response filters, that's another kind of filter which we didn't do in our area. And correlation convolution. So all signal processing, digital signal processing functionality, they will implement.

**Speaker 2** 07:52

Okay.

**Speaker 1** 07:52

Most of these functions require the data to be multiplied and added. You know, we have coefficients, we take the sample, multiply with the coefficient and then add. And you know, we get the real and imaginary part.

**Speaker 2** 08:06

Okay.

**Speaker 1** 08:08

So the function is generally multiply accumulate. So these chips will do that. Okay, very fast. So this is to increase the performance. General purpose DSP processes are used and they can do this in a single clock. Very quick. The whole FIR filter can be implemented in one single clock.

**Speaker 2** 08:38

Okay.

**Speaker 1** 08:38

You give them the coefficients and they will do that.

**Speaker 2** 08:41

Okay.

**Speaker 1** 08:42

Multiply accommodator function. And there are some floating point multiply accumulate functions processes also now.

**Speaker 2** 08:53

Okay.

**Speaker 1** 08:53

Especially from Texas Instruments. Those are the ones IUI has used in that.

**Speaker 2** 09:01

Okay. So.

**Speaker 1** 09:05

Each tap, you know, requires. So if you have sixteen tap filter, it just requires sixteen cycles.

**Speaker 2** 09:13

Okay.

**Speaker 1** 09:18

Yeah, I think I have said everything here. So let me just give you an idea of. Quick idea about various architectures of ieds.

**Speaker 2** 09:36

Okay.

**Speaker 1** 09:38

There may be some variations depending on the specific application, but manufacturers have come to now what we call. They have given different names. When we introduced it, we called it general purpose hardware. And you will see that same hardware can be used to implement any kind of id. Just change the software in that case. Okay, so this is first architecture where you have one A to D converter for each channel. So you may have three voltages and three currents and sometimes neutral also depending on the number of channels. But each channel looks like this. You have a voltage buffer, filter sample and hold A to the control converter and then you go to the processor. Okay, so this is the architecture. So separate A to D converter used for each input channel. Okay. It's required when speed is very important. Speed is. But nowadays, you know, lot of id's are using it because all these components are not.

**Speaker 1** 10:49

And also the fact that we are using general purpose hardware, that has even reduced the cost quite a bit. Okay. And if the amount of calculation done within then waiting for samples is a problem. Right? Because if you look at this architecture where we're using one A two D converter versus if I use separate A to D, this is four times more. You have to wait. First you have to do one channel, then second, then third, then fourth. So you know it has to be done sequence. Right. But if you have a TO D for each channel, you can just do in one shot. So this is Four times more time it takes, right? And if you are using a high sampling rate, your sampling interval is very small, okay? And you have to perform all your calculations within that before the next sample comes. Right? It has to be done within that. So for that, sometimes you have to use this. Now there are relays actually because of this issue.

**Speaker 1** 12:01

They skip a sample. They will skip a sample. They will still sample at high rate. But when you are doing calculations, they will do it in two sampling intervals, not one. So they will skip a sample in that case. Another aspect of these id's is self testing. Remember in the very beginning I said that these id's just sit there and watch, you know, every one over eight thousand second. If you are using eight thousand hertz sampling rate. But they only act when something is wrong. Something happens. It doesn't happen that often. Okay, so how do you know whether they are dead or alive? You don't know, right? They can be dead and when they are required, they are not there. So self testing is actually big thing. So what happened previously, the technician used to go to the field and test on periodic basis.

**Speaker 2** 13:12

Okay.

**Speaker 1** 13:12

They will actually go there and perform the test to make sure that they work.

**Speaker 2** 13:17

Okay.

**Speaker 1** 13:17

Now the question becomes, do you test them daily or do you test them every month? Did you test them every six months or test them in any year? Once a year, Nobody knows. Right? So self testing is introduced especially when they became digital. Okay. So microprocessor based ieds offer this unique feature where digital hardware, all this hardware can be self tested.

**Speaker 2** 13:49

Okay.

**Speaker 1** 13:51

Once in a while you can periodically perform the self testing of these devices. And obviously that increases the availability.

**Speaker 2** 14:01

Okay.

**Speaker 1** 14:02

Of these relays. So self monitoring is implemented in two stages. First, complete diagnostic check when you just turn it on. So it will even perform the calibration at that time. Complete diagnostic check of everything, all the components that make sure they are working. And the second one is continuous. When you put it in service, then continuous self checking operation happens. Okay, what do they test? Read only memory. Okay. How can you test that? Computing checksum of wrong context and comparing it against a factory. Because it's read only memory, you can't really write anything to it. Okay, so and then if there is a discrepancy, that means something is wrong with that. Then there is random access memory where you can read something, write something and make sure that you read back the same thing.

**Speaker 2** 15:09

Okay.

**Speaker 1** 15:10

That means the random access memory is working in that case. Okay, Then you can do the power supply testing. Okay, you can actually have a one channel just for the power supply here, this is the power supply. Go through the multiplexer, A to B converter and C the output. If the power supply is supposed to be between say four to five volt, if it is not four to five volt here, that means something is wrong with the power supply. Because remember, power supply is extremely important for this whole thing to work. If you don't have power supply, your hd, all these things won't work, right? So if that happens, then you can, you know, provide that A to B conversion time testing.

**Speaker 2** 16:10

Okay.

**Speaker 1** 16:11

If your A to D converter is not working, generally what happens is when you ask, when you give a pulse to it to start conversion and then after some time it should give you an output. If it doesn't give you an output, something is wrong, compound, it gets stuck, it doesn't do anything. So that's one type of testing which is the time testing. Failure to complete conversion within the specified time obviously indicates a failure. The other type of conversion is to check the accuracy which is done at the time of calibration.

**Speaker 2** 16:54

Okay.

**Speaker 1** 16:54

You apply a known signal to it, okay. And see what is the output. Okay. So all those tests are done there. Then all these devices have settings in them. Let's say you know, you are checking, you are measuring the voltage and say voltage has to be within certain range, okay. If it goes below or above or same thing for frequency, frequency has to be close to sixty hertz.

**Speaker 2** 17:27

Okay.

**Speaker 1** 17:28

So when you are comparing, then you are comparing against a setting. And all those settings are stored in the memory, which is eeprom, electrically erasable programmable read only memory.

**Speaker 2** 17:45

Okay.

**Speaker 1** 17:46

So you can actually have two sets of those settings at two different places. And then you compare them. If they are exactly same, that means they are fine, nothing has changed in them. Then there is analog gain and offset, that's more during calibration you can apply a DC like signal, okay. And then you know, you can compare the recovered signal. That way you can see whether there is a gain or offset or anything. So that's done during calculation. So there are checks like that you can do. So these id's have self checking, they are sitting there, once in a while they will come out. And actually way back we did some work where we figured out what is the best self testing time interval. You know, how often self testing should be done. And that was done based on the reliability of these.

**Speaker 2** 18:56

Okay.

**Speaker 1** 18:59

Let'S talk about the soft head and out main. So this was the hardware, you know, software obviously is sitting in the processor. There are couple different Types of softwares, okay? Data acquisition software, which basically controls all these components, okay? When to sample, okay? If there is a multiplexer selects the particular input, controls the I to the converter, reads the data, okay? That's the data acquisition software. It basically acquires the sampled values from the data acquisition and stores in the memory, okay? This is one part of the software and that obviously will depend on the architecture. Then there is a processing software which will have algorithm, okay? And then it will do some ancillary functions also. For example, breaker maintenance, keeping log of whether circuit breaker is open or closed, okay? Frequency deviation from nominal.

**Speaker 1** 20:15

So it does all kind of storage and other ancillary functions. There are a whole lot of those, okay? And then there is a HMI setting, which is the setting software, which is big thing, okay? Comparing your data from the system, say voltage or frequency with the setting, okay? So that software there then communication is big part, okay? As I said, they now have separate processes just to do the communication. And now we are talking about networking. It's not just standard communication. So there is that and self checking we talked about, okay? Then there is the logic, okay? Depending upon the complexity of the situation, there could be a logic. If this happens and this happens, or this happens, you do this, okay? And then you can add cybersecurity part here also there is a cyber security software nowadays that is there, okay? So those are types of softwares that are there.

**Speaker 1** 21:32

So let me just give you an idea of what id's use, you know, what are their philosophies, design philosophy? As I said, there is general purpose hardware. So if you noticed here, okay, all we are doing is acquiring voltage and current signals, okay? Depending upon the type of ied, sometimes you may acquire only one voltage signal and one current signal. Sometimes you may acquire three voltage signals and three current signals, or three voltage signals and four current signals if you are acquiring neutral current also.

**Speaker 2** 22:15

Okay?

**Speaker 1** 22:15

So it's very much structured, you know, so you could basically have these blocks. You don't need separate hardware. You don't need to design separate hardware for each of these situations. You could use what we call general purpose hardware.

**Speaker 2** 22:37

Okay?

**Speaker 1** 22:37

So if you look at this, this is just like wavo blocks. You see the front end, Each one is a block, what we call current module and a voltage module, okay? That's the isolation and scaling part and filtering part each channel. And then there are four of these data acquisition blocks. It can take four channels. Ten have individual A to B converter or ten have only one A to B converter. But each One is a block. So let's say you need eight channels. You just choose two of those and then they connect to what we call the DSP or microprocessor. Okay, so the data acquisition module, because it takes four channels. So it looks like this, right? This was one suggestion you could have, as I said, one A to D converter for each channel. Right? So the components. This is the part that was done when this concept was introduced in nineteen ninety, not nineteen ninety, even before that.

**Speaker 1** 24:01

Right? So analog filters were switched capacitor, cutoff frequency you can set by the external clock. Remember, with the switched capacitor, the value of resistance can be controlled. Right? Sample and data acquisition. Sample and hold. Acquisition time is one point five microsecond. Group rate. Because of the capacitor, it will droop. Okay? It's zero point five microvolt per microsecond. So very little droop happens.

**Speaker 2** 24:34

Okay.

**Speaker 1** 24:35

And then input and output. This is multiplexer four to one, right? A to B converter was twelve bit at that time, which was quite good at that time. Nowadays, as I said, they use up to twenty bits.

**Speaker 2** 24:49

Okay?

**Speaker 1** 24:50

Conversion time of six microseconds. So six microseconds. If you are using four of those in twenty four to microsecond, it will do the conversion for four channels, right? And. And then you control everything using TMC three hundred twenty C twenty five, which is a dsp.

**Speaker 2** 25:13

Okay?

**Speaker 1** 25:14

Now they have actually even higher versions of that and how you control it using the I O port of the processor.

**Speaker 2** 25:25

Okay?

**Speaker 1** 25:25

It has a sixteen bit I O port. Then you can control everything using those bits. Okay? So for control signals, sample and hold needs one bit because you are either sampling or holding zero or one, right? You are in the track mode or you are in the hold mode. And then multiplexer needs two bits, as I mentioned, right? You are selecting one of the four channels. A to D converter needs two times four bits.

**Speaker 2** 25:59

Okay?

**Speaker 1** 26:00

Two times four bits, two times to start the conversion and then to stop the conversion. Right? So for each one it will need two bits. Two times four is eight. So total you need eleven bits to control. But this is a sixteen bit aio, so you are okay. And then for input control, you need twelve bit for A to D and four bits for the status. So sixteen bits. So this is another version of the same thing, right? You can have a communication card also at the same time to perform the communication. And then your data creation card is here. And then you have your modules. Everything sits in an industrial grade PC, right? So this was general purpose hardware. Let me think when we introduced this in nineteen eighty seven or eighty eight.

**Speaker 2** 27:16

Okay.

**Speaker 1** 27:17

And it actually became an industry standard. So now almost every manufacturer is doing this. They have, you know, some call it universal hardware. You know, they call it by different names, but they are basically starting to do this. You know, modules for each one, depending upon what ID you want to produce, they just put those modules together and connect them.

**Speaker 2** 27:46

Okay.

**Speaker 1** 27:47

There was another concept which was called open system relate. Okay, Similar concept, but they also tried to generalize the software.

**Speaker 2** 28:02

Okay.

**Speaker 1** 28:03

Because if you look at it, what does the software. Major components of the software, there are phaser calculations and then some logic. So they try to, you know, do that. Also hardware plus the software as well. And even the some characteristics, they tried to do that. Okay, so this was the open systems relay. But as I said, majority of the manufacturers have started doing that now.

**Speaker 2** 28:38

Okay.

**Speaker 1** 28:39

For example, GE uses same concept, they call it universal relay. Other manufacturers have same concept. They call it a, you know, with a different name. Okay, so hopefully this gives you some idea about the IED hardware. Okay, so what we are going to do next is talk about synchro phases. Okay, so let me just give you a quick idea about that. And we are not going to start that topic today. We will do that on Wednesday. But we have a little bit of time. I can explain why and what we want to do with synchro phases.

**Speaker 2** 29:28

Okay.

**Speaker 1** 29:29

What is the concept behind that? So it happened after the blackout, I don't know, two thousand three blackout. Who remembers that? Yeah, so it happened here, two thousand three blackout. After that, you know, the concept of synchro phasers was started. Okay, so let's talk about a power system, you know, because it's all interconnected. You see, everything is interconnected.

**Speaker 2** 30:06

Right?

**Speaker 1** 30:07

So previously, prior to that, they had some idea about, you know, what is the voltage, for example, at this bus and what is the voltage at this bus? What is the voltage at this bus? At least the magnitude. They had some idea that what is the magnitude? But there was no concept of the relationship between this voltage and this voltage, which if you think now is actually ridiculous because it's all connected. Right? So what if we can know, you know, let's say this angle is zero, this angle is sixty. You know, just take numbers. This angle is thirty. Right. But if I know not only the magnitude at the same time, I also know the angles to a common reference. So this is my common reference.

**Speaker 2** 31:08

Okay.

**Speaker 1** 31:09

V one is here, V two is here, V three is here, V four is here. So I know all these with respect to. And if I know this, it actually gives a lot of power to the operator who are controlling the system. And you will know way back before things start to happen, okay? Before the system becomes unstable. And this is exactly what happened to two thousand three, blackout, okay? They had no. What we call situational awareness of the system, okay? So now in our ieds at the local level, as I mentioned, we can do the sampling at the same time. Because within the ide, I can use one clock, okay? I don't need to go anywhere if this is id, and if sitting here, I use one single clock, and let's say I'm acquiring some voltages and currents, I can know their relationship with each other. I know how they are with respect to if I sample at the same time, okay? But it will still have no relationship with this, right?

**Speaker 1** 32:30

Because this sampling is only happening here at the same time. This ID here is using its own sampling clock, which is not synchronized to this one, right? So this relationship will not be maintained. So, you know, if, say I'm measuring this voltage is zero degree, I'm measuring this one, it's supposed to be sixty degree, but I will not get sixty degree angle. I'll get something different. So there will be no relationship between them, okay? So this was what was happening, okay? So now in order to get this, I have to make sure that whenever I am sampling here at the same time, I am sampling here and here and here and here and here, everywhere in the system. So I need one single sampling clock for the entire system. And how do I get that? I will get that through gps.

**Speaker 2** 33:39

Because.

**Speaker 1** 33:39

GPS signal is everywhere, right throughout the world. So I can actually synchronize the sampling here and here. If I can do that with the GPS clock, then I can make sure that they are sampling at the same time. If that happens, then I will get this zero, this sixty, exactly the values what they are. So I get much better idea of the system, how the system is and how it looks like at any particular instance. And these things are known as synchro phasors. That means the phasors are now synchronized to a common reference. And that's the one we will talk about in our next lecture. How do we achieve it? What happens? And also give you some idea about the GPS clocks. And then there is the standard IEEE C thirty seven point one eight which specifies the requirements for synchro phases. What are the requirements for synchro phases? And you will see that what we talked about in the frequency measurement comes back all those algorithms come back.

**Speaker 1** 35:05

Okay, so those are the topics and then substations and communication. If I have time, I will talk about cyber security just to give you some idea. Okay? At least you can study on your own. Okay, so I'm going to post these from today's lecture. I think I have posted everything else, right? You have the frequency one. Because you're not going to find this stuff anywhere. No book is there. Maybe one day I will write one, but I don't know when I will have time. Right, so all this material will be there for you to, you know. So I'll post this.

**Speaker 2** 35:55

Okay?

**Speaker 1** 35:56

You have any questions for me? But today. Okay, one more thing. I'm going to post the solution for assignment number two. This is what I want you to do. I have already posted solution for assignment one. You probably seen that. Okay, this is what I want you to do. Each one of you look at your solution. What you have look at the solution I have posted and you compare and then you send me an email. What was different? Okay, I'm going to look at it also, but I want you to look at it too. Okay, there are two things why I want you to do that. One, obviously you get to self assess yourself. Okay, self. Secondly, the whole idea is for you to understand. This will force you to look at the thing you haven't done and understand them. Because in this course that's all my aim is for you to understand things. So take a look, compare and you do. Do that for both assignments.

**Speaker 1** 37:16

I'm going to post assignment two solution also today. Okay, do that and send me a quick email. I don't want detailed thing. Okay, don't write an essay.

**Speaker 2** 37:28

Okay.

**Speaker 1** 37:28

And no excuses. Nothing like that. Oh, I forgot this. I didn't do this. Nothing, just very simple what you did correct, what you did not do correct.

**Speaker 2** 37:40

Okay.

**Speaker 1** 37:41

And make sure you understand from the solution. It's very simple stuff anyway. Okay, so do that and send me an email to each one of you. Yeah. Is it just for final submission? Not like the in class final submission? Yeah, because well, if you didn't do everything in the final submission, some of you may have done some portion in the class and you didn't repeat that in the final submission. Then consider both. But you did right in both.

**Speaker 2** 38:15

Okay.

**Speaker 1** 38:16

And send me a quick email again. Make sure you don't write an essay. Just very simple stuff. But you did, you got it right. And actually what you didn't get it right is important for me. Okay, but you got it right. I'm happy. But very good. But you didn't get it right. You tell me that. More important, that this is the part you didn't get it right and you understand it now. Okay, Send me a quick email. Sooner you do it better. And we will do the same thing for your third assignment, which will be on Wednesday.

**Speaker 2** 38:53

Okay.

**Speaker 1** 38:54

We will do the same thing and then take home exam will be there. You will get a lot of time for that.

**Speaker 2** 39:01

Okay.

**Speaker 1** 39:02

Okay, do that. Send me a message. Send me an email. Assignment is only regarding next one is Wednesday. For least error square, not frequency. Yeah, only the phasor calculation. So all three assignments are about phasor calculation.

**Speaker 2** 39:31

Okay.

**Speaker 1** 39:31

Frequency will be maybe in the final one. In the final. Okay, So I think if you have no question, then we will stop here.

**Speaker 2** 39:52

It.