Yüksek Gerilim Kablo Sistemleri için Arıza Erken Uyarı Sistemli Yeni Nesil Ekran Bağlantı Kutusu Geliştirilmesi

Development of a New Generation Intelligent Link Box (iLinkBox™) with Early Warning System for High Voltage Cable System

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Abstract

Link Boxes are integral accessories of HV/EHV cable systems. Any failure in link box proper performance can lead to failure of costly HV cable system. Sheath voltage limiter (SVL) failure, condensation and corrosion, water ingress and copper theft are among the cause of link box failures. Also link boxes are favourable point for partial discharge measurement of HV cable accessories and monitoring of bonding system's voltage/current. This paper presents development process of a new type of intelligent link box (iLinkBox™) with early warning system of different parameters including partial discharge in cable accessories, voltage/current of bonding system, water ingress, counter of impulses passing through SVL etc. iLinkBox™ will be able to continuously monitor the condition of link box and HV cable termination and joints then alarming unusual behaviours before the catastrophic failure.

Geniş Özet

Ekran Bağlantı kutuları (EBK) yüksek gerilim (YG) kablo sistemlerinin çok önemli bir parçasıdır. YG kablo ekranları özel bir biçimde bu kutuların içeresinde direkt olarak topraklanır, SVL (Sheath Voltage Limiters) (koruyucu parafudr) ile toprağa çaprazlama yöntemleri ile bağlanır. Kısa devre ve geçici aşırı gerilimlerden kaynaklı kablo sistemi arızalarında bağlantı kutusunun kritik rolü vardır. EBK'lar YG kablo ek veya başlıklarına yakın bir yerde yeraltı menhol de, beton bir kaide üzerinde veya tünel duvarına monte edilir. Sahadaki zor şartlar (bölgeye su basması, aşırı sıcak veya soğuk), montaj hatası veya üretim hatalarından dolayı bu panolar arızalanabilir. EBK'lar arızalandığı zaman yüksek gerilim kabloları da arızalanır; örneğin EBK içerisine su girişi olursa şayet, bakır baralarda paslanma meydana gelir, kontak dirençleri aratar ve bakır baralardan kısa devre akımı geçtiği zaman patlama meydana gelir ve topraklama sistemi çökmüş olur ve sonuç olarak yüksek gerilim kablo sistemi de arızalanır.

Ekran bağlantı kutularındaki olası hataları tespit etmek için çevrimdışı ve çevrimiçi yöntemler vardır. Çevrimdışı yöntemde kablo enerjisi kesilir ve her kutunun bakımı ekip tarafından yapılır (gözle muayene, DC dayanım testi, kontak direnç testi, SVL durum kontrolü vs.). Bu yöntemde belli bir aralıklarla (yılda bir defa) eğitimli bir ekip sahadaki tüm kutuların kontrollerini yapması gerekir. YG kablo güzergâh uzunluğu ve ekran bağlantı kutu sayısına göre bu iş çok üzün ve maliyetli olabilir. Ayrıca bu yöntemde her bakımdan sonra herhangi bir hata ortaya çıkarsa bir sonraki yıla kadar tespit edilemez. Çevrimiçi yöntemlerde ise kablo sistemin enerjisi kesmeden ekran bağlantı kutu durumu izlenebilir. Bu kapsamda bazı çalışmalar yapılmıştır (örneğin SVL kaçak akımını veya bonding sistemi akımlarını izleyerek).

Diğer yandan yüksek gerilim kablo ek ve başlıkların arıza tespitinde kullanılan kısmı boşalma (PD) ölçümü uzun zamandan beri kullanılmaktadır. Kısmı boşalma ölçümü yeni kurulan kablo sisteminde döşeme sonrası hataları (örneğin kesik, çizik, kirlenme gibi) tespit etmek için etkili bir yöntemdir. Halen hizmet vermekte olan mevcut kablo sistemlerinde yapılan kısmi boşalma ölçümü, yalıtımda oluşan bozulmanın yararlı bir göstergesidir. Çevrimiçi kısmı deşarj ölçüm sistemleri (PDM) son zamanlarda EHV kablo sistemlerinde yaygın olmaya başlamıştır örneğin DEWA gibi iletim firmaları bu tip izleme sistemlerin kurulmasını zorunlu hale getirmiştir. Piyasada birçok ticari PDM sistemi olmasına rağmen bunların çoğu yüksek yatırım gerektirmektedir ve kurulumu ve işletimi ileri deneyimli personele ihtyaç vardır. Ayrıca, şimdiye kadar, yüksek gerilim kablo sistemlerinin ayrılmaz bir parçası olan ekran bağlantı kutularına özel bir izleme sistemi geliştirilmemiştir. Bu çalışmada, ekran bağlantı kutusunun izlenmesi için ve yüksek gerilim kablo aksesuarlarının kısmi deşarj seviyesini ölçmek için ekonomik ve kullanımı kolay bir alarm sistemi geliştirilmeye hedeflenmektedir. Yeni arıza erken uyarı sistemli akıllı ekran bağlantı kutusu (iLinkBox ™) sayesinde, YG kablo ekran akımı ve voltajı, darbe gerilim olayları, su girişi, sıcaklık ve nem, iç basınç, bağlantı kutusu kapak durumu ve yüksek gerilim kablonun kısmi deşarj seviyesi dahil olmak üzere çeşitli parametrelerini sürekli olarak izlenmesi mümkün olacaktır. SCADA sistemine entegre edilmiş basit kullanıcı arayüzü ve gelişmiş karar verme algoritmaları sayesinde, son kullanıcı karmaşık verilerle değil, yalnızca basit alarmlarla ilgilenir. Bu şekilde ekran bağlantı kutuları ve kablo aksesuarlarındaki olası arızlar çok ciddi hasarlara neden olmadan önce tespit edilir.

***Anahtar kelimeler**: YG kablo başlık ve ek, akıllı ekran bağlantı kutu, kısmı deşarj, bakım, izleme, toprklama sistemleri, dış kılıf parafudru.*

1. INTRODUCTION

A sheath bonding system is a system to minimize the induced circulating current and to protect insulation of HV cable outer sheath against overvoltages from lightning, switching, and fault surges [1].

Link boxes are the enclosures in which bonding and grounding of sheathes of HV cable joints or terminations made through removable links. Link boxes also may contain sheath voltage limiters (SVL) to limit lightning or switching overvoltages. Link boxes are installed close to HV cable joints or terminations and may be installed in places such as underground manholes, aboveground structures/pedestals, or tunnel walls [2].

Any failure in link box proper performance can lead to failure of costly HV cable system [3]. The link box may fail due to exposure to the harsh environment, including moisture, heat, UV, manufacturing defect, or mechanical impact. Common failures that can be inspected externally include corrosion, physical damages, and moisture ingress [1]. Some real cases of link box failures (including ingress of water into link box) leading to cable joint failure has been investigated in [4]. Many utilities would require that SVLs be housed in explosion proof link boxes to withstand short-circuit conditions. Some utilities have experienced some damage to their systems due to the failure of SVLs under short circuit conditions [5]. Inappropriate selection of SVL in bonding system is a main cause of link box failure and damage to sheath of EHV cable during short circuit and transient voltages [6]. Excessive sheath voltage limiters (SVL) failures were observed in at least three of the 275 kV circuits in National Grid network, which in turn led to extra cost, more frequent and longer maintenance interventions [7].

It may be more cost efficient to prevent failures with regular maintenance, than to perform corrective maintenance after a failure has occurred. CIGRE Working Group B1.50 [1] has listed some preventative maintenance methods of bonding systems. Offline methods (not energized cable system) including periodic visual inspection, contact resistance test, DC withstand test and SVL integrity tests are the common practices in HV cable industry. Online methods (energized cable system) including measuring sheath currents, fiber optic embedded SVL monitoring or measuring SVL leakage current, use of DTS (Distributed Temperature Sensing) data to check condition of bonding system, visual or thermal images have been used in some practices. Some works such as [8] and [9] have discussed sheath current monitoring to diagnosis of HV cable faults.

On the other hand, PD detection is the best method for XLPE cable insulation condition evaluation recommended by experts and scholars all over the world, IEEE, IEC, CIGRE and other international power authority organizations [10]. Online PD monitoring of EHV cable systems has received more attention in recent years. Some utilities like DEWA now requires continuous real time PDM (partial discharge monitoring) system in 400 kV cable systems [11].

There are many commercial monitoring systems (specially PDM systems) available in market but most of them suffer from high cost, complexity of installation & operation and need to highly experienced staff to operate whole system and interpret the collected data. Also, up to now, there is no special monitoring system for link boxes which are integral part of HV cable systems.

This work has been started to develop an economic, simple-to-operate & install alarm system for the link box itself and partial discharge level of HV cable terminations and joints.

2. DEVELOPMENT OF iLinkBox™ COMPONENTS

2.1. Partial Discharge Sensors

Two types of partial discharge sensors were specially designed for this study. The First sensor is an insulator type PD sensor with built-in HV divider [2]. As can be seen in Fig.1 (a) this sensor contains a soft ferromagnetic core with primary and secondary winding to pick up PD signals from copper busbars of link box connected to high voltage cable screen. This sensor also contains a HV voltage divider for measuring induced voltages in bonding system. This output also can be used to provide synchronization signals for PD measuring board. Also, output of this divider can be used for counting number of lightning impulses passing through SVLs inside link boxes so condition monitoring of SVL is possible. These insulator type sensors are mounted below copper busbars of link box instead of common support insulators. Special attention was made to design the sensor to meet the High voltage requirements of link boxes, e.g.

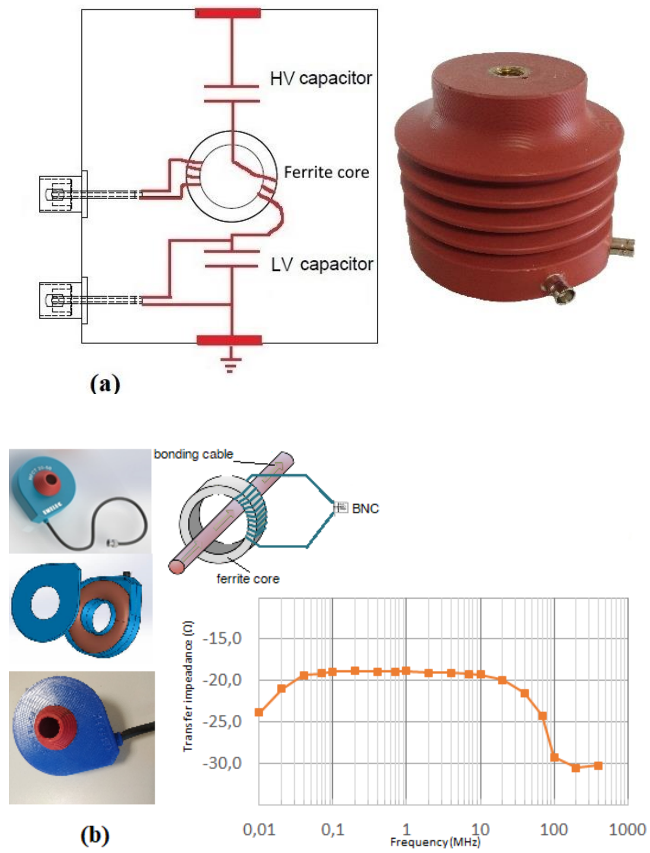

Fig. 1: Partial discharge sensors: (a) insulator type PD sensor with built-in voltgae divider (b) HFCT

not having metallic parts near energized parts that can affect lightning performance of link box.

The 2nd sensor which has been designed is a HFCT type PD sensor as shown in Fig. 1 (b). High frequency current transformers (HFCTs) are widely used as sensors in PD detection and monitoring systems applied to HV equipment [12]. Some aspects of these sensors for PD measurement in different apparatueres are described in litaratures like [13]- [15].

This sensor is needed in some of direct earthing link boxes which only inductive PD sensing is available and type (a) PD sensor cannot be used (only HV divider part of sensor will be used). Designed special HFCT for current project has large internal diameter (ϕ44mm) makes it applicable for different size of bonding cables. A silicone plug is used to fix the sensor to wide range of bonding cables. The sensor is constructed with a copper body to provide RF shielding and improved performance in noisy environments. Specially designed ferrite core and primary and secondary windings provides a high-performance partial discharge sensor for range of 0.4-20 MHz. Wide frequency response of the sensor, low background noise, tight installation around bonding cables (thanks to its flexible silicone ring embedded in internal part) and not having metallic parts (that can affect HV performance of link box) are the advantage of this type of PD sensor.

2.2. AC Current measuring sensor

A 20/0.1 ratio epoxy current transformer has been designed to measure the induced currents circulating inside link boxes so sheath current monitoring of bonding system will be made. Any increase or unbalance in sheath currents now will be monitored. These sensors are mounted around bonding cables inside link box and are designed to measure the sheath currents during normal operating of

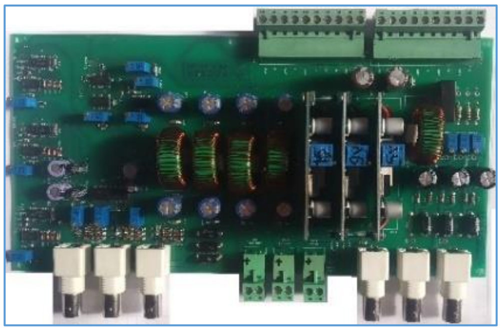

Fig. 2: Current & Voltage Measuring and Pulse Counting Board

Fig. 3: PD measuring board including 3 input channels, a input sync. channel

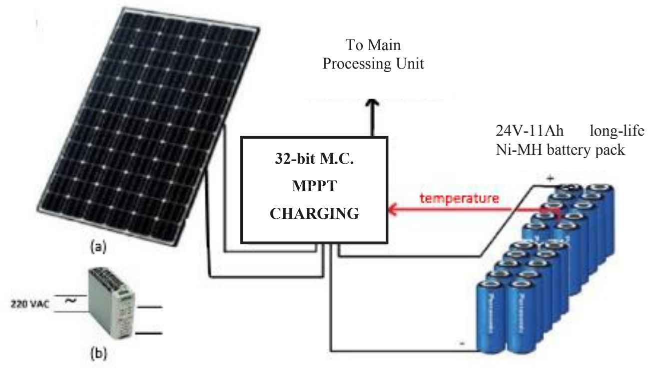

Fig. 4: power supply system, (a) charging from solar panel, (b) charging form street lighting line

bonding system and abnormal conditions (e.g. SVL failure that can lead to increased or unbalanced currents).

2.3. Other Sensors

There are other useful sensors inside iLinkBox to monitor the condition of link box:
- A water sensing sensor to detect water ingress into link box,
- A temperature & humidity sensor that can be used to evaluate condensation issues or other abnormal condition,
- A switch embedded in lid of link box to show the open/close statues of lid, this data can be used to check the unauthorized opening of link box.
- A Pressure sensor to detect any increase of internal pressure of link box due to internal arc,

All output data of these sensors are directly sent to main processing unit (MPU) of iLinkBox.

2.4. Current-Voltage Conditioning and Pulse Counting Board

An analog conditioning board was developed to convert received signals from AC HV voltage divider and AC current measuring sensors to readable data for main processing unit (MPU):

- AC Output signals of insulator type voltage divider are connected to three input channels of conditioning board. The input signals are passed from a protection circuit to where they are amplified to increase the accuracy of measurements. Finally, the signals are rectified to be read via main processing unit (MPU).
- output signals of voltage divider are also sent to a comparator and pulse generation circuit to generate signals to be read via counter in main processing unit (MPU). All impulses exceeding specified level are counted as an impulse incident. This circuit enables the iLinkBox to count the number of impulses voltages due to incident of lightning/Switching or fault surges in bonding system so condition monitoring of SVL will be possible.
- AC out signals of current measuring sensors are connected to three input channels of conditioning board. After passing from a protection circuit, signals are rectified to be read via main processing unit (MPU). Any change in AC current in bonding system (e.g. SVL failure) can be detected.

The conditioning board also contains a synch voltage selection circuit to provide appropriate synch signal for PD measuring board (synch voltage will be selected from bonding system voltage or current). It also contains SMPS voltage regulators to regulate the DC power supply of all components (with different supply voltage level). A LC type low pass filter has been added to reduce the noise level of power supply circuit. Two-layer PCB mounted board can be seen in Fig.2.

2.5. Partial Discharge Measuring Board

The PD measuring board has three input channels connected to the insulator type PD sensors or HFCT sensors. An input protection stage is followed by signal conditioning, filtering, and amplification of the high frequency partial discharge signals from PD sensors (Fig.3). Signal sampling and processing is done by an i.MX28 processor running Linux . It also receives the synch signal from the conditioning board to synchronize the measured PD signals with AC voltage of bonding system. The board includes an ethernet output port to communicate with main processing unit (MPU).

Special attention has been made to develop a noise discrimination algorithm to reduce the false alarming due to received background noise.

2.6. Power supply system

Providing energy for all electronic components is critical for a reliable system. After consulting with different customers and considering target project requirements, a battery storage system charging from solar panel or street lighting line has been selected. This system can be seen in Fig.4. A 32-bit ARM microprocessor was programmed to charge the 24V-11 Ah durable Ni-MH battery with specialized algorithms to ensure long life operation of battery pack (at least 10 year). MPPT (Maximum Power Point Tracker) algorithm was used in case of solar charging.

2.7. Main Processing Unit (MPU)

An ARM Cortex M type microcontroller (which is low-cost and energy-efficient) has been selected to process all incoming data from sensors, conditioning board and partial discharge measuring unit. An advanced decision-making algorithm for alarming has been embedded in this unit. Alarming algorithms and triggering levels can be customized in SCADA user interface according to project specifications. Two remote data communication methods (between on-site iLinkBox and SCADA database in control center) has been selected in this project according to target project requirements. A fiber optic communication method can be used when the project owner can allocate a FO line for alarming system (new cable projects). If this option is not feasible then a wireless GSM/GPRS communication method can be used for iLinkBox. In

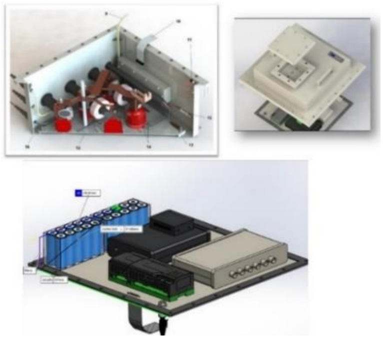

Fig. 5: design details of iLinkBox and layout of components inside

Fig. 6: iLinkBox™ prototype

this method it is necessary to install an antenna outside of link box where the GSM signals can be reached. It is to be noted that an energy saving plan has been used in this project. Data communication operations can increase the energy consumption, so intervals of data sending to SCADA database from each iLinkBox has been increased to one hour in this project.

3. MECHANİCHAL DESGİN OF iLinkBox™

Mechanical design of link box body and lid was made to meet all requirements of international and national standards. AC/DC withstand levels, impulse voltage withstand level, IP class and other requirement of project has been considered in this process.

Fig.5 shows the schematic view of designed link box. All sensitive electronic components have been placed in upper separate compartment in lid of link box to be isolated (shielded) from HV side of link box (lower compartment). All electronic components are mounted on a removable baseplate in upper compartment. All sensor output cables are entering a junction box on wall of lower compartment. All signal lines are protected by surge protection devices inside junction box. Connection between upper compartment (electronic devices) and junction box made via a multiple core signal as well as a fiber optic cable. By removing these cables, the lid of link box (as well as all electronic devices) can be pulled out for any setting or maintenance work on site. There is small terminal box on top of upper compartment. There are three PD output in this terminal box as well as a synch output for local partial discharge measurement on site. This option is useful to perform deep investigations of partial discharge measurements when an alarm has been received from iLinkBox.

4. DEVELEOPED iLinkBox™ PROTOTYPE

Fig.6 shows a prototype of current project. Also overall logic of iLinkBox system has been shown in Fig.7. Prototype iLinkBox has been exposed to some functional and type tests in factory environment to evaluate its performans before on-site pilot tests. 20/25 kV AC/DC tests, contact resistance tests and other link box type tests have been applied successfully. Also some functional tests including battery system check-up, functionality of different sensors & alarms and communication check-up have been done in SCADA screen.

5. CONCLUSION

iLinkBox™ can be used to continuously monitor & alarm different parameters of link box including current & voltage of sheathes, number of impulse voltage incidents, water ingress, temperature & humidity, internal pressure, link box lid status, and partial discharge level of HV cable accessories. Thanks to embedded advanced decision-making algorithms, final user will only deal with simple alarms not complex data. Simple user interface integrated to SCADA system enables the operator to receive alarms concerning unusual behaviour before catastrophic failure of link boxes and cable accessories.

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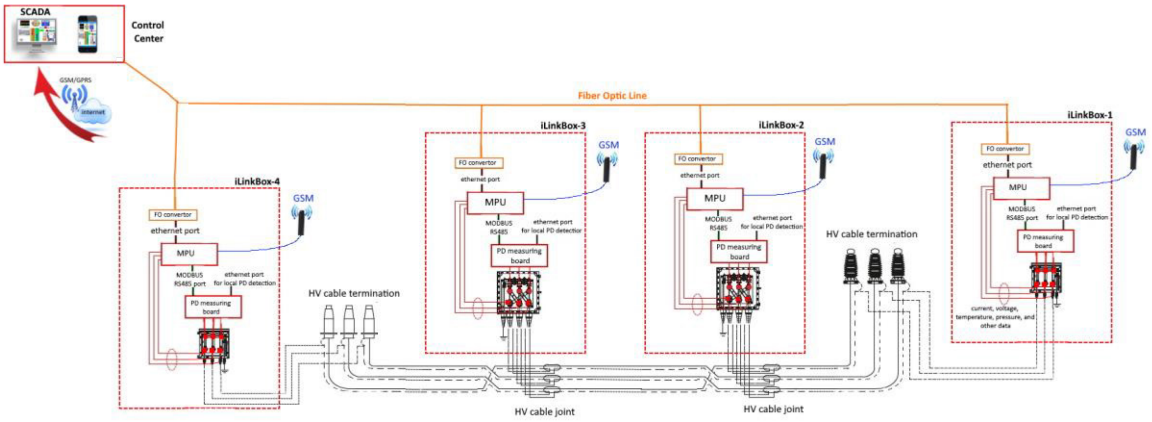

Fig. 7: Overall structure of iLinkBox alarming system for a sample Project

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Dr. COLIN SMITH

Dr. Colin SMITH, received the Bachelor's Degree in Electronics and Electrical Engineering from University of Manchester in 1990 and Ph.D degree in 1993. In 1995, he joined the IPEC comapny as managing director up to now. With 19 publications his is currently involved in research in the fields of Partial Discharge (PD), development of test and permanent monitoring equipment for HV cables and switchgear, partial Discharge signal analysis and diagnostics.