**Некоммерческое партнерство «Российский национальный комитет Международного Совета по большим электрическим системам высокого напряжения» (РНК СИГРЭ)**
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# ОТЧЕТ

об участии в работе электронной Сессии СИГРЭ-48 Международного Совета по Большим Электрическим Системам
Париж, Франция, 24.08-03.09.2020

Отчет подготовил:

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«Оборудование для магистральных и
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# СОДЕРЖАНИЕ

## Сфера деятельности и основные направления Исследовательского комитета А3.

В сферу деятельности Исследовательского комитета (ИК) А3 входят вопросы теоретических и экспериментальных исследований, проектирования, создания и применения высоковольтного оборудования и компонентов для магистральных и распределительных сетей электроэнергетических систем переменного и постоянного напряжения, включая взаимодействие с сетью и другим оборудованием в нормальных и аварийных режимах работы, обеспечение надежности, проведение испытаний, обслуживание, управление активами и прочее.

Основные направления деятельности ИК А3 связаны с исследованием коммутационных аппаратов, измерительных трансформаторов, токоограничивающих устройств, ограничителей перенапряжений, конденсаторов, изоляторов и высоковольтных вводов и включают в себя анализ применения новых конструкций, материалов, технологий, повышение надежности электрооборудования, исследование вопросов старения, продления срока службы оборудования и др.

Тематическая область ИК А3 включает четыре основных направления, а именно:

- новые технологии (в том числе выключатели постоянного тока);
- управляемость высоковольтного оборудования;
- диагностика и мониторинг состояния оборудования;
- оценка надежности, включая срок жизни стареющего оборудования в нормальных и экстремальных условиях.

## Введение

В период с 24 августа по 3 сентября 2020 года в онлайн-формате в виде вебинаров состоялась 48-я Сессия Международного Совета по Большим Электрическим Системам (СИГРЭ). Накануне мероприятия было зарегистрировано более 2500 участников (рис.1), что значительно превышает первоначальные прогнозы, 800 человек присутствовали на торжественном открытии в прямом эфире, и в среднем почти 1500 человек ежедневно подключались к электронной сессии.

Представители Национального Исследовательского комитета НИК А3 РНК СИГРЭ приняли участие также приняли участие в следующих мероприятиях:

1. Торжественное открытие 48-й Сессии.
2. Презентации докладов по предпочтительным темам направления ИК А3.
3. Заседание Исследовательского комитета ИК А3.

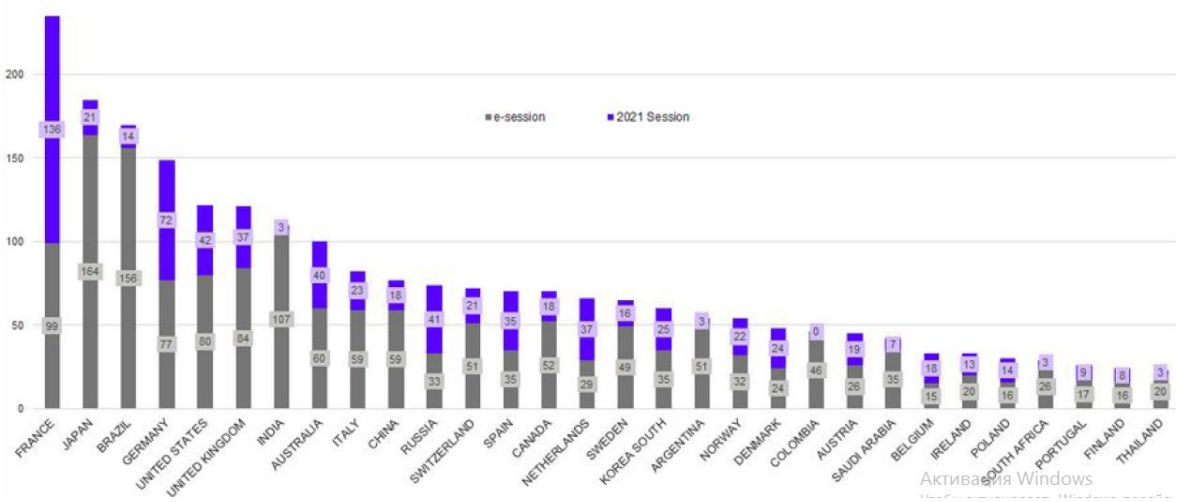

Рис.1. Количество зарегистрированных участников (30 стран)

**1. Торжественное открытие 48-й Сессии.**

24 августа состоялось торжественное открытие сессии. Основная часть заседания была отведена докладу ключевого спикера - Анны Олхофф, руководителя отдела стратегии, климатического планирования и политики Датского технического университета – партнера программы Организации Объединенных Наций по окружающей среде (ЮНЕП). Анна Олхофф представила доклад ЮНЕП о разрыве в уровнях выбросов 2019 года.

Также в ходе открытия президент СИГРЭ Роб Стефан представил лауреатов премии СИГРЭ 2020 года и ознакомил слушателей с техническим содержанием электронной сессии: тематиками вебинаров 16 исследовательских комитетов, обучающих семинаров и воркшопов.

**2. Презентации докладов по предпочтительным темам направления ИК А3.**

По направлению Исследовательского комитета А3 на 48-й электронной сессии СИГРЭ было представлено 45 докладов, в том числе 5 из России. Основными вопросами, обсуждавшимися в процессе дискуссии, были проблемы, отраженные в трех предпочтительных темах (ПТ)О. объявленных двумя годами ранее:

ПТ 1 (19 докладов). ПЕРСПЕКТИВНЫЕ РАЗРАБОТКИ В СФЕРЕ ОБОРУДОВАНИЯ ДЛЯ ПЕРЕДАЧИ И РАСПРЕДЕЛЕНИЯ ЭЛЕКТРОЭНЕРГИИ

- Выключатели постоянного тока среднего напряжения.
- Способы повышения надежности.
- Разработка оборудования со сниженным воздействием на окружающую среду.
- Альтернативы элегазу (SF6) для дугогасящей и изолирующей среды.

ПТ 2 (23 доклад). УПРАВЛЕНИЕ СРОКОМ СЛУЖБЫ ОБОРУДОВАНИЯ ДЛЯ ПЕРЕДАЧИ И РАСПРЕДЕЛЕНИЯ ЭЛЕКТРОЭНЕРГИИ

- Диагностика, мониторинг и прогнозирование состояния оборудования.

- Влияние окружающих и эксплуатационных условий.

- Опыт и меры предотвращения избыточных нагрузок и перегрузок.

ПТ 3 (3 доклада). ВЛИЯНИЕ РАСПРЕДЕЛЕННОЙ ГЕНЕРАЦИИ НА БАЗЕ ВИЭ И СИСТЕМ НАКОПЛЕНИЯ ЭНЕРГИИ НА ОБОРУДОВАНИЕ МАГИСТРАЛЬНЫХ И РАСПРЕДЕЛИТЕЛЬНЫХ СЕТЕЙ

- Новые и перспективные технологии для коммутационных аппаратов и другого оборудования.

- Создание интеллектуального оборудования.

- Влияние распределенной генерации на базе ВИЭ и систем накопления энергии на требования, предъявляемые к оборудованию.

Перечень докладов представлен в ***Приложении 1***, аннотации - в ***Приложении 1***.

## 2. Заседание Исследовательского комитета А3

Онлайн-заседание Исследовательского комитета А3 проходило в течение 2 дней – 25 августа и 1 сентября. В заседании приняли участие члены комитета А3, являющиеся представителями национальных комитетов стран-участниц СИГРЭ, а также представители других комитетов СИГРЭ, гости.

Программа двухдневного заседания комитета А3 включала в себя обсуждение вопросов, связанных с текущей деятельностью комитета и планов на будущее: отчеты руководителей рабочих групп, проведение будущих коллоквиумов и семинаров. Темы двухдневного заседания были обозначены в докладе руководителя ИК А3 Ненада Узелака.

### *2.1 Роль международных организаций в решении энергетических проблем Африки*

Доклад был представлен Кевином Клейнхансом - руководителем рабочей группы WG Africa, созданной Всемирным банком для изучения проблем беднейших африканских стран в области электроэнергетики.

В отличие от других частей мира, нынешняя плотность населения в странах Африки к югу от Сахары невысока и делает электрификацию на основе энергосистем дорогостоящей во многих сценариях. Эти страны могут извлечь особую выгоду из продолжающейся смены парадигмы энергетической системы на более дешевую возобновляемую энергию, цифровизацию, включая жизне-

способный контроль микросетей, и все большее понимание роли рынков по сравнению с монополиями в электроэнергетических системах. Огромные гидро- и солнечные природные ресурсы в Африке делают международные или даже межконтинентальные межсетевые соединения особенно привлекательными. Это может положительно повлиять на интеграцию возобновляемых источников энергии также в Европе и на Ближнем Востоке. Вместе Всемирный банк и СИГРЭ разработали процесс расширения передачи ноу-хау для Африки, основанный на предоставлении доступа к объективному и актуальному техническому опыту разными инновационными способами.

В рамках рабочей группы осуществляется взаимодействие с менеджерами, инженерами, экономистами, плановиками, а также академическими кругами в разных учреждениях в Африке к югу от Сахары:

• Министерства энергетики, регулирующие органы и законодатели

• Электроэнергетика, вкл. операторы систем передачи и распределения генераторы, поставщики энергии и электрические бассейны

• Крупные промышленные и горнодобывающие потребители электроэнергии

• Администрации города

• Компании по установке и обслуживанию микросетей / наносетей и общественные группы деревенских лидеров

• Университеты и центры передового опыта.

Рабочая группа определит региональные приоритетные области на основе результатов опроса и приоритетных проектов, определенных Всемирным банком. В настоящее время решается важная задача по привлечению экспертов для передачи знаний и созданию местных национальных комитетов СИГРЭ в качестве средства достижения этой цели.

Подчеркивается, что высокие темпы экономического роста в Африке нуждаются в надежной электроэнергии. Цифровизация позволяет Африке совершить скачок в развитии и использовать новейшие технологии и системы управления для энергосистем. Основное внимание уделяется передаче знаний для содействия развитию электроэнергетического сектора и доступа к электроэнергии в Африке посредством систематического распространения результатов СИГРЭ, ориентированных на целевые группы.

***2.2 Консультативный совет по электроэнергетике***

Руководитель группы – Роберт ле Руа (Ирландия). Цель UAB - быть «голо-

сом» энергопотребителей. Задача состоит в том, чтобы обсудить потребности энергопотребителей, сопоставить эти потребности и сформулировать стратегический план услуг, чтобы информировать об их нуждах и проблемах Исследовательский комитет А3.

В настоящее время рабочая группа насчитывает 10 человек и открыта для включения в нее новых членов.

***(Green Book on Swithgear)***

Технический комитет СИГРЭ в сотрудничестве с издательством Springer, продолжает публикацию Зеленых книг по направлениям соответствующих Исследовательских комитетов СИГРЭ.

В 2016-2017 г.г. были изданы следующие Зеленые книги:

- *High Voltage Equipment* (Высоковольтное оборудование), ИК А3;
- *Insulated Cables* (Изолированные кабели), ИК В1;
- *Substations* (Подстанции), ИК В3;
- *HVDC and Power Electronics* (Постоянный ток и силовая электроника), ИК В4;
- *Protection and Automation* (Релейная защита и автоматика), ИК В5;
- *Distribution Systems and Dispersed Generation* (Системы распределения электроэнергии и распределенная генерация), ИК С6.

На заседании руководитель ИК А3 Hiroki Ito объявил о выходе в 2018 году Зеленой книги по направлению комитета А3, включающую в себя следующие разделы:

1. Деятельность комитета А3
2. Устройства коммутации
3. Механизм коммутации
4. Выключатели переменного тока
5. Системы аварийной сигнализации и оповещения (AC DS and ES)
6. Ограничение тока КЗ
7. Управляемая коммутация
8. Выключатели высокого напряжения постоянного тока
9. Управление сроком службы коммутационного оборудования
10. Новые технологии

***2.2 Деятельность рабочих групп***

На заседании были заслушаны отчеты руководителей следующих рабочих

групп:

РГ А3.36 Мультифизическое моделирование для расчета превышений температуры.

РГ изучила контрольный ориентир мультифизического моделирования и упрощенные технические средства для прогнозирования результатов испытаний на превышение температуры, описывающие современные технологии в отношении распредустройств среднего и высокого напряжения и критические параметры, влияющие на точность моделирования. Работу предполагается завершить в 2019 г. Руководитель, Martin Kriegel (CH)

ОРГ А3/В5/С4.37 Состояние системы при рассогласовании фаз. (Объединенная рабочая группа исследовательских комитетов А3, В4, С4). Руководитель - Anton Janssen (NL).

Руководитель информировал о завершении работы группы в 2018 г.

РГ А3.38. Включение шунтирующих конденсаторов в магистральных и распределительных сетях. Руководитель - Edgar Dullni (DE)

Рабочая подгруппа TF1 завершила онлайн-опрос, начатый в феврале 2018 года, получены ответы от 48 респондентов для 14 классов напряжения. В среднем каждый респондент осветил по 3 класса напряжения, что позволило описать 157 случаев.

Рабочие подгруппы TF4 и TF5 собрали информацию об альтернативных емкостных коммутационных устройствах и применении блоков фильтров.

Рабочая подгруппа TF3 собрал и проанализировала данные о работе элегазовых и вакуумных выключателей с учетом длительного срока эксплуатации

РГ А3.39. Применение и опыт эксплуатации металл-оксидных разрядников. Руководитель - Robert le Roux (IE).

В марте 2018 года состоялось третье заседание рабочей группы, созданной в 2.

Составлена форма анкеты для анализа надежности и отказа на основе данных, которые предполагается получить в онлайн-опросе. Обобщены результаты предыдущих опросов.

РГ А3.40. Технические требования и опыт эксплуатации коммутационного оборудования постоянного тока среднего напряжения. Руководитель - Christian Heinrich (DE).

Рабочая группа была сформирована в 2018 г. и предполагает закончить свою деятельность в 2021 г. В состав рабочей группы входит российский специалист – В. Кучинский. Перед группой поставлены следующие задачи:

1. Собрать и проанализировать опыт эксплуатации коммутационного оборудования постоянного тока напряжением до 52 кВ.

2. Проанализировать существующие прототипы коммутационного оборудования постоянного тока мощностью до 52 кВ.

3. Проанализировать технические требования к коммутационному оборудованию постоянного тока для различных конфигураций системы.

4. Сравнить технические требования к автоматическим выключателям постоянного тока среднего напряжения по сравнению с выключателями переменного тока и выключателями постоянного тока высокого напряжения.

5. Разработать рекомендации по требованиям к испытаниям коммутационного оборудования постоянного тока высокого напряжения.

РГ А3.41: Прерывания и коммутации при применении коммутационного оборудования, не содержащего элегаз. Руководитель - René Smeets (NL).

Рабочая группа была сформирована в 2018 г., заседания еще не проводились.

В задачу группы входит:

Сбор доступных данных о прерывании и переключении оборудованием с различными смесями газов без SF6, анализ преимуществ и недостатки разных решений SF6, анализ эксплуатации, осуществляемой в рамках пилотных проектов и оценка эффективности коммутаций в течение ожидаемого срока службы, долгосрочной стабильности и влияние на работу по техническому обслуживанию, связанному с коммутацией, разработка рекомендаций для коммунальных предприятий, а также рекомендаций для разных стандартов.

На заседании комитета А3 была заслушана также информация по родственной тематике, которую представил руководитель объединенной рабочей группы ОРГ D1/B3.57 - Диэлектрические испытания газонаполненных систем постоянного тока высокого напряжения.

Секретарь ИК А3 Франк Рихтер проинформировал о принятии Техническим комитетом СИГРЭ решения о создании нескольких новых рабочих групп:

- WG A3.42. Failure analysis of recent AIS instrument transformer incidents;
- WG A3.42. Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems.

Кроме того, Техническим комитетом рассматривается вопрос о создании еще четырех новых рабочих групп:

- WG A3.XX. Identification of frequency response characteristics of conventional and non-conventional voltage instrument transformers;
- WG A3.XX. Temporary operation Of High Voltage Equipment above Maximum Operating Voltage;
- WG A3.XX. Procurement, Quality Control, Commissioning of Equipment;
- WG A3.XX. Technical evaluation of generator switching technologies in power generation plants.

Для участия в новых рабочих группах приглашаются заинтересованные эксперты.

***2.3 Сообщения представителей организаций-партнеров ИК А3***

В ходе закрытого заседания комитета А3 были заслушаны сообщения представителей ряда организаций – партнеров СИГРЭ.

Представители CIRED и IEC TC17/SC17A сделали сообщения о предстоящих событиях, организуемых этим организациями в ближайшем будущем, разрабатываемых ими стандартах, планируемых к созданию новых рабочих групп, в том числе с участием ИК А3.

***2.4. Сообщение о предстоящих событиях с участием ИК А3***

Представитель японского национального комитета А3 D. Yoshida проинформировал участников заседания о деталях конференции, проводимой совместно комитетами А2, А3, В1, В2, В4, С4 и D1 23 -27 апреля в 201г году Хакодате, Япония (http://www.cigre2019.jp). Конференция посвящена новые трендам в передовых технологиях для эффективного управления экономичными и устойчивыми энергетическими системами высокого и сверхвысокого напряжения переменного и постоянного тока

Представитель Румынии I.Hategan представил презентацию о предстоящем коллоквиуме СИГРЭ, организуемом комитетами СИГРЭ А1, А2, А3, В1, В2, В3, D1 совместно с CMDM) который состоится 9-11 сентября 2019 года в Бухаресте, Румыния (http://www.cigre.org.ro).

Представитель индийского национального комитета А3 Tayagi Ravindra Kumar представил информацию о планируемом в 2021 году коллоквиуме ИК А3 в Дели, Индия.,

Представитель российского национального комитета А3 А.Дробышевский сделал презентацию – приглашение провести объединенный коллоквиум Исследовательских комитетов СИГРЭ А1, А3 и /D1 в 2023 году в Москве. Предложение было принято. Все детали по организации (сроки, место проведения, предпочтительные темы) будут обсуждены позднее.

**Заключение**

По итогам работы комитета А3 на 48-й сессии СИГРЭ, как и на предыдущей, можно отметить следующие наиболее обсуждаемые ключевые вопросы:

1. Высоковольтное оборудование для новых системных условий.

2. Управление сроком службы оборудования для магистральных и распределительных сетей.

3. Применение средств информационных технологий для разработки и управления высоковольтным оборудованием.

ПРИЛОЖЕНИЕ 1

Перечень докладов ИК А3, представленных на сессии СИГРЭ-48

**Предпочтительная тема 1. Перспективные разработки в сфере оборудования для передачи и распределения электроэнергии**

**A3-101 EDISON: A New Generation DC Circuit Breaker**
L. GRABER, T. DAMLE, C. XU, J. WEI, J. SUN, M. MEHRABAN, Z. ZHANG, M. SAEEDIFARD, S. GRIJALVA, J. GOLDMAN, Q. YANG, K. SCHODER, F. PENG, M. STEURER – *США*

**A3-102 Environmental Performance of Dead-Tank Circuit Breakers with SF6 and Alternative Gases**
E. LARUELLE, C. GREGOIRE, L. DARLES, Y. KIEFFEL - *Франция*, V. HERMOSILLO - *США*

**A3-103 VARC DC circuit breaker – a versatile concept for nonzero current interruption**
L ÄNGQUIST– *Швеция*

**A3-104 Innovative T&D Switching Equipment and Development of its Testing Technology**
A.B. HOFSTEE, R.M. NIJMAN, N.A. BELDA, B. BAUM, R.P.P SMEETS - *Нидерланды*

**A3-105 Low loss DC circuit breakers and DC GIS equipment**
M. KOSAKADA - *Япония*

**A3-106 First CO2neutral 145 kV and up to 63 kA Dead Tank Circuit Breakers based on Vacuum Switching and Clean Air Insulation Technology**
TH. HEINZ, S. GIERE, J. TEICHMANN, D. HELBIG, S. KOSSE – *Дания*, C. WEEKS, T. RAK - *США*

**A3-107 Fault current limiters for electrical grids 220 kV on the base of the fast-acting highvoltage explosive commutators**
А.В. МУРОВ, В.Е. ФОРТОВ, А.В. ШУРУПОВ, А.В. КОЗЛОВ, К.А. ЗИМИН, Н.Л. НОВИКОВ - *Россия*

**A3-108 Studying the characteristics of non-traditional current and voltage converters for digital substations**
А.А. ЯБЛОКОВ, В.Д. ЛЕБЕДЕВ, Г.А. ФИЛАТОВА, С.Н. ЛИТВИНОВ, Е.Е. ГОТОВКИНА, Н.В. ЛЕБЕДЕВА - *Россия*

**A3-109 Power plants Modernization by Smart integrated vacuum generator breaker switchgears**
K. VENNA, H. URBANEK, F. RADEMACHER - *Дания*, J. ROMÁN, I. CÁRCAMO, G. URQUIZA - *Испания*

**A3-110 Development and Electrical Performance Research of a 12kV C4F7N/CO2 Ring Main Unit**
Z. LI, E. DONG, R. ZHANG, Z. ZHANG, Y. WANG, X. YAN, Y. Z, D. AN, H. HUANG, X. Xu - *Китай*

**A3-111 Experience of Capacitive Current Switching of EHV and UHV AC Circuit Breaker in Power System and Test**
G. LI, S. L. YAO, C. H. ZHANG, P. R. WANG, D. F. YAN - *Китай*

**A3-112 Basic aspects of switching with series-connected vacuum interrupter units in high-voltage metal-enclosed and live tank arrangements**
J. TEICHMANN, R HUTH, T. GOEBELS, J. WEISKER, P. G. NICOLIC - *Дания*

**A3-113 Interrupting Performance Evaluation of High-Voltage Gas Circuit Breakers Using CFD Simulation and Data Analysis Technique**
J. H. PARK, S. Y. WOO, H. K KIM, M. J. HA, K. B. SEO - *Корея*

**A3-114 The First Development of SF6-free 170 kV 50 kA 60 Hz GIS with Fluoronitile (C4F7N) Mixtures**
H.E. JUNG, H.S AHN, Y.G. KIM, J.U. YEUN, J. CHOI - *Корея*, J OZIL, M. PERRET, K.BOUSOLTANE, G PERNAUDAT - *Франция*

**A3-115 Case Study – Improving Reliability of Circuit Breaker by using Controlled Switching and removing Pre Insertion Resistor (PIR)**
JIVESH KHANNA, AMANDEEP SINGH, RAKESH KUMAR, R.K. TYAGI - *Индия*

**A3-116 Innovative SF6 Free Load Break Switch with Shunt Vacuum Interruption (SVI) Technology**
**C. PREVE, R. MALADEN, D. PICCOZ – *Франция,***

**A3-117 Return of experience of the SF6-free solution by the use of fluoronitrile gas mixture and progress on coverage of full range of transmission equipment**
J. OZIL, F. BIQUEZ, A. FICHEUX, Y. KIEFFEL, C. GREGOIRE – Франция, L. DREWS – *Германия,* R. LUESCHER - *Швейцария*

**A3-118 C5 fluoroketone based gas mixtures as current interrupting media in high voltage switchgear**
P.S. STOLLER, M. SCHWINNE, J. HENGSLER, F. SCHOBER, H. PETERS – *Германия*, T.HD. BROUN – *Швейцария*, W. ALBITAR - *Германия*

**A3-119 Theoretical and Practical Behaviour of Ecofriendly SF6 Alternatives in High Voltage Switchgear**
S. BRYNDA, Y. PARK, H. SOHN, T.H. SONG, X. YE, J.D. MANTILLA - Швейцария

**<u>Предпочтительная тема 2. Управление сроком службы оборудования для передачи и распределения электроэнергии</u>**

**A3-201 CIGRE Reliability Survey on Equipment**
Hiroki ITO, Nenad UZELAC, Frank RICHTER, Robert le ROUX, Wayne PEPPER, Li PENG, Anongpun MAN-IM, Ioan HATEGAN – *от SC A3 CIGRE*

**A3-202 Operational Experience, Field Test and EMT Simulation for EHV ShuntReactor Switching**
G. BLANCHET, R. OTTERSTEN, D. P. LYSHEIM, T. M. OHNSTAD - *Норвегия*

**A3-204 In-service Diagnosis of Grading Capacitor Dielectric Deterioration**
K. WILLIAMS, P. MOORE - *Великобритания*

**A3-205 Circuit Breaker De-Rating Assessment under High DC Time Constant**
T. FAIREY, Z. EMIN – *Великобритания*, J. KELLIHER, M. V ESCUDERO - *Ирландия*

**A3-206 Actual use survey and maintenance practice of circuit breakers for frequent switching applications**
S. TSUKAO, M. NAKAMURA, M. NAKAI, A. SHIMAMURA, D. YOSHIDA J. KIDA – *Япония*

**A3-207 A campaign for the ageing evaluation of station hollow core composite insulators after a number of years of service**
G. CAMPOPIANO, G. PELLICCIONE, M. MARZINOTTO – *Италия*, E. MOAL, J. SEIFERT, G. ROCCHETTI – *Дания*

**A3-208 Overvoltages research in switching modes of cable and mixed overhead-cable lines, power transformers, shunt reactors and capacitor banks of 110-750 kV and development of a controlled switching device for the above electrical equipment**
С. АРУТЮНОВ, А. МЕРЗЛЯКОВ, И.НАЗАРОВ, В. СМЕКАЛОВ, С. БАЛАШОВ, Е. ЕРОХИН - *Россия*

**A3-209 X-ray inspection of operating high-voltage oil-filled circuit breakers**
Л.А. ДАРЬЯН, П.В. ГОЛУБЕВ, Е.П. ГРАБЧАК, Р.М. ОБРАЗЦОВ - *Россия*

**A3-210 Online monitoring of paper-oil insulated current transformers**
I. AYERDI, I. HUERTA, J. MENDIZABAL, J.M. NOGUEIRAS - *Испания*

**A3-211 Influence of Contact Heating on Main Circuit Resistance Measurement and Dynamic Contact Resistance Measurement in High Voltage Circuit Breakers**
T. CHENG, W. GAO, L. JI – *Китай*

**A3-212 Research on Simulation Testing Method of System Level's Strong Electromagnetic Disturbance in Substations**

L. CHENG, J. LIU, A. GUO, W. XU, H. WEI, J. LU, AND S. REN - *Китай*

**A3-213 Operational Aged Switchgear With The Age Up To 50 Years - Investigations, Testing, Results Considerations For The Design And Operation Of Old and New Switchgear**
T. GRÄF, R. SCHILLER **-** *Германия*

**A3-214 Investigation of ferroresonance oscillations in the systems with electromagnetic potential transformers by experimental and calculation methods**
А. РОТБЛЮТ, Г. ВЕДЕРНИКОВ, О. ПЕТРОВА, В. СОЛОМЕИН, Л. ТУПОНОГОВ, А. СИВКОВ - *Россия*

**A3-215 Development of 362kV 63kA 60Hz Self-Blast Breaker without additional capacitors to prevent ferro-resonance by improving the SLF performance**
J. H. YOON, J. K. PARK, J. U. CHOI, H. S. AHN, Y. G. KIM - *Корея*

**A3-216 Damping Performance of VFTO using Magnetic Rings in 800kV GIS**
J. W. KIM, J. K SEONG, J. K KIM, K. R KWON, D. J SIM - *Корея*

**A3-217 Approach & Experience of IoT Based Predictive Maintenance Technologies in Power Distribution Network**
H.C. SHARMA, Y. K. GUPTA, S.K. ATRI, P.K. SINGHAL, R.M. BHANAGE, V. K. DIXIT, A. BASU - *Индия*

**A3-218 Technical-Economic Study on Spark Gaps Replacement by Surge Arresters on Pole-Mounted MV/LV Transformers**
W. CHABANE, F.REBBOUH - *Алжир*

**A3-219 Pollution and Humidity Effects on Air Insulated Switchgear (AIS) of MV/LV Substations**
F.REBBOUH, W. CHABANE - *Алжир*

**A3-221 Digital Disconnector and smart sensors: example of integration in the condition base asset management cloud tool**
T.PEGOURET - *Франция*, E.STELLA - *Италия*

**A3-222 External flashover of a 245kV live tank circuit breaker**
D. CHUN, C. PONS, H. DIGARD - *Франция*

**A3-223 Monitoring of asymmetric short circuit currents at a hydro power plant using electronic fibre optical current transformers**
T.NEUMEIER - *Германия*, T.HEID, F.RENAUD, M.VO - *Швейцария*, M.YANIN - *Россия*

**A3-224 Accuracy study of a combined low-power instrument transformer in different climatic and pollution conditions**
T.HEID, M.VO - *Швейцария*, B.PAYA, L.BASUYAUX - *Франция*, M.YANIN - *Россия*

**A3-225 Development of Light Asset Models based on Data Mining**
F. LIMA, G. MARQUEZIN, T. MAUFFREY - *Франция*

**Предпочтительная тема 3. Влияние распределенной генерации на базе ВИЭ и систем накопления энергии на оборудование магистральных и распределительных сетей**

**A3-301 First 170 kV / 50 kA GIS with Clean Air and Vacuum Interrupter Technology as a Climate-neutral Alternative to SF6**
K. KIM, B. CHOI, S. HEO - Корея, F. EHRLICH, K. POHLINK, M. KUSCHEL, T. RANK - *Германия*

**A3-302 Benchmarking the suitability of a Bi-Stable Disc Spring as Novel Ultra-Fast Actuation Principle**
H. MENNE, C. M. FRANCK - *Швейцария*

**A3-303 Performance tests of circuit-breakers for controlled switching**
J. KIEFER, H. HEIERMEIER, S. KOTILAINEN, M. STANEK - *Швейцария*,
U. PARIKH - *Индия*, A. DANESH - *Германия*

ПРИЛОЖЕНИЕ 2

Аннотации докладов ИК А3, представленных на сессии СИГРЭ-48

**Предпочтительная тема 1. Перспективные разработки в сфере оборудования для передачи и распределения электроэнергии**

### A3-101 EDISON: A New Generation DC Circuit Breaker

L. GRABER, T. DAMLE, C. XU, J. WEI, J. SUN, M. MEHRABAN, Z. ZHANG, M. SAEEDIFARD, S. GRIJALVA, J. GOLDMAN, Q. YANG, K. SCHODER, F. PENG, M. STEURER – *США*

The lack of viable DC circuit breaker technologies limits the implementation and use of DC grids. Therefore, several R&D projects are underway worldwide to develop DC circuit breakers. Particularly, in this paper we describe four innovative ideas and technologies in order to arrive at highly compact and efficient hybrid DC circuit breakers to make them available for DC grid applications. This hybrid DC circuit breaker features a power stack of semiconductors and associated energy absorption elements, which is normally bypassed by a fast mechanical switch to minimize on-state losses. This fast mechanical piezo-actuated switch uses supercritical fluids as a dielectric medium and is therefore expected to carry several kiloamperes of continuous current while it can open, without interrupting current, within several hundred microseconds. Next, we are placing a controllable voltage source in series with the power stack to commutate the rising fault current from the mechanical switch into the power stack. Finally, we follow the increasing voltage withstand capability of the opening mechanical switch with the incremental voltage buildup across the power stack over time. This approach significantly reduces the overall fault current peak as opposed to turning off the power stack at once only when the mechanical switch reached the complete open position. The expected outcome is a more efficient breaker with improved fault handling characteristics. The four technologies are described in detail and explained how synergistic effects improve the overall switching performance. Applications for such technology is listed and the benefit briefly explained.

### A3-102 Environmental Performance of Dead-Tank Circuit Breakers with SF6 and Alternative Gases

E. LARUELLE, C. GREGOIRE, L. DARLES, Y. KIEFFEL - *Франция*, V. HERMOSILLO – *США*

Life cycle assessment results are presented for different HV Dead-Tank (DT) circuit breaker technologies including SF6, a CO2/O2/C4F7N gas mixture and a combination of vacuum interrupters with technical air insulation. Comparisons are made of the environmental performance of DT outdoor circuit breakers with 72,5 kV maximum rated voltage, 40 kA short-circuit current and 2000 A continuous current. This is a voltage class for which SF6-free products have been available for nearly a decade. This is also the rating that has been proposed for phase-out by CARB in the year 2025. At this time, there are around six-hundred 72,5 kV DT vacuum/air circuit breakers installed in North America and their market penetration has been limited by price and performance considerations.

Design features that affect the material content, dimensions, power usage, emissions and maintenance requirements are presented and compared for each of the technologies. Circuit breakers described as 0,5 Mpa and 0,6 Mpa vacuum have material masses 61% and 32%, respectively, greater than those insulated with SF6 and a gas mixture. The mass increase for solutions using vacuum interrupters is due to dimensional requirements associated with reduced dielectric withstand of internal air insulation. All circuit breakers with alternative insulating gases offer a reduction in climate change impact in the range of 50 to 60%. Ozone depletion is equal for SF6 and CO2/O2/C4F7N gas mixture and lower for vacuum/air. Human toxicity, particulate matter, ionizing radiation, ozone formation, acidification, eutrophication, fresh-water ecotoxicity, water consumption, land usage and resource depletion are higher for vacuum/air circuit breakers compared to the other options.

### A3-103 VARC DC circuit breaker – a versatile concept for nonzero current interruption

L ÄNGQUIST– *Швеция*

The paper describes a new interrupter concept, the “VSC Assisted Resonant Current (VARC]”, having the capability to instantaneously interrupt non-zero current. A standard vacuum interrupter has been equipped with a low-voltage power electronic converter combined with a resonant circuit, which generates an artificial current zero-crossing in the arc current in the vacuum interrupter when a sufficient contact gap has been established.
Using an ultra-fast actuator, the operation time from trip command to current neutralization is only a few milliseconds at a voltage level of 40 kV. A current interruption capability exceeding 10 kA has been demonstrated.
It is shown that the proposed VARC concept requires a low number of semiconductor devices, offering an attractive bill of materials without compromising the provided performance.
A module based on the concept was tested at an independent laboratory in 2018. Some test results are presented in the paper.
The paper provides a technical overview of the proposed concept and its applications in DC and AC systems.

**A3-104 Innovative T&D Switching Equipment and Development of its Testing Technology**

A.B. HOFSTEE, R.M. NIJMAN, N.A. BELDA, B. BAUM, R.P.P SMEETS - *Нидерланды*

In this contribution, a number of technology innovations in T&D switchgear have been identified. In almost all cases, the ongoing energy transition is the main driver of these innovations. In this contribution, based on test-experience and overviewing the industry, innovations are grouped by a number of drivers that each have their impact on testing technology.
These drivers are the following:
• Increase of ratings: the ongoing trend of co-existence of micro-, local- and supergrids. The consequences for testing of switchgear for UHV and very large current are highlighted;
• Offshore transmission: compactness and reliability are requirements stretched to the limit for this application. Very long cables for AC and HVDC power transmission, even in a multi-terminal topology will have impact on switchgear;
• Health safety and environment: here, the major switchgear related discussion is on SF6 replacement and reduction of electrical losses. Various issues related to SF6 replacement will be highlighted. In addition, a recent project, intended to quantify the hazard of aluminium busbars in power stations affected by long duration fault arcs, is described;
• HVDC and power electronics: circuit breakers are going to be installed in multi-terminal HVDC grids. Recent testing of HVDC breakers, regarding the complete interruption process is described;
• Digitalization: switchgear is going to be communicating with the IEC 61850 communication protocol. This will impact testing for which laboratories need to prepare. The introduction of smaller micro-electronics (sensors, IED) more closer to primary HV components and its high-frequency transients need careful consideration regarding operation, endurance and lifetime.
• Resilience and fault mitigation: Large scale outages are less and less accepted by society but still occur frequently. Resilience against severe weather conditions, vandalism and cyber-attacks calls for resistant equipment and robust mobile equipment/substations that can be deployed very rapidly still having an extreme degree of readiness and availability. Novel technologies of ultra-fast actuators enable a new generation of fault current limiters.

**A3-105 Low loss DC circuit breakers and DC GIS equipment**

M. NAKAI, Y. NAKAI, Y. MAKINO, A. MIURA, T. MINAGAWA, M. KOSAKADA - *Япония*

Multi-terminal high voltage direct current (HVDC) systems are expected to expand into many applications, including offshore wind power networks. In such systems, DC circuit breakers (DC CBs) play an important role to separate a faulted section rapidly from the system, while keeping a remaining portion of the network in continuous operation. Various types of DC CB have been proposed and developed in recent years, each having its advantages and disadvantages. Minimizing losses, which is important both for the overall efficiency of the system and from an environmental point of view, is a vital consideration in these CB designs. This paper introduces two types of systems, a mechanical system and a hybrid system. In the mechanical type, a comparison was made between a combined design and a modular design, with a voltage class up to 525/600 kV. Performance was verified up to the 160/200 kV-16 kA class. The hybrid type is characterized by

both low losses and high-speed interruption under all conditions. These parameters were verified for interruptions up to 6.7 kV-9 kA.
The application of compact equipment is required especially for offshore wind power systems, and DC GIS is one of the solutions for compact equipment. In Japan, there is a need to apply DC GIS due to the fact that the available land area is small, and also because salt pollution is severe. DC GIS at 250 kV and 500kV were developed and have been in operation since 2000 in Japan. A new 250 kV DC GIS was recently developed and put into operation in the New Hokkaido-Honshu HVDC Link in 2019. These applications and experiences obtained from the projects are presented in this paper. The development specifications, technical and structural considerations, application concepts, and commutation SW technology will be introduced.

**A3-106 First CO2-neutral 145 kV and up to 63 kA Dead Tank Circuit Breakers based on Vacuum Switching and Clean Air Insulation Technology**

TH. HEINZ, S. GIERE, J. TEICHMANN, D. HELBIG, S. KOSSE – *Дания*,
C. WEEKS, T. RAK - *США*

This paper describes performance and test results of newest products which use vacuum-switching and technology up to 145 kV and 63 kA and complete CO2-neutral insulation with clean and dry compressed air. It shows the newest products: 145 kV / 40 kV Dead Tank Breakers, 145 kV / 50 kA gas-insulated switchgear and concludes with the 145 kV / 63 kA Dead Tank circuit breakers. The CO2-neutral Dead Tank circuit breaker replaces existing equipment easily without any changes in the layout. Based on existing 50 kA vacuum interrupters an upgraded version for 63 kA vacuum interrupter was developed by usage of simulation tools for arc behavior and magnetic fields. With the vacuum interrupter as key element the Dead Tank circuit breaker design was developed with the help of mechanical multi-body and electro-magnetic simulations. The specific conditions for the clean air insulation system has been considered accordingly. With a development prototype Dead Tank circuit breaker high-power switching tests have been performed (e.g. T100 short circuit current test duties) as well as dielectric and mechanical tests.
The vacuum switching technology has significant advantages compared to gas circuit breaker applications. The vacuum circuit breaker is the preferred solution for frequently operated switching and high short-circuit interruptions because of low contact erosion. The vacuum interrupter is a sealed for life component and thus completely maintenance free throughout the full-service life of more than 30 years. For low temperature applications below -25° C, the vacuum technology in combination with clean air insulation offers outstanding performance because no additional measures are necessary. With the new technologies – high-voltage vacuum switching and clean air insulation – upcoming switchgear are future proof with respect to environmental and technical aspects. Both technologies combined ensure outstanding switching performance, safety and reliability with excellent long-term stability and very low environmental and health impact. All these aspects are eminent for future demands of power grid.
High-voltage vacuum interrupters up to 245 kV (single break) will be available in the next years commercially. The world’s first vacuum interrupters for 170 kV / 50 kA and 245 kV / 63 kA were shown on CIGRE 2018. Now a 145 kV / 50 kV dead-tank circuit breaker will be shown on CIGRE 2020. Based on recent developments on vacuum switching and clean air insulation technology new CO2-neutral products will replace common SF6 switching equipment in the next decades.

**A3-107 Fault current limiters for electrical grids 220 kV on the base of the fast-acting high-voltage explosive commutators**

А.В. МУРОВ, В.Е. ФОРТОВ, А.В. ШУРУПОВ, А.В. КОЗЛОВ, К.А. ЗИМИН, Н.Л. НОВИКОВ – *Россия*

New fault current limiting device with a voltage of 220 kV (FCL-220) based on explosive type high voltage switches, is presented. The device is intended to limit the short-circuit current to acceptable values for a time not exceeding one half-period of the supply frequency at electric power facilities. The analysis of the electro-technical scheme of the developed fault current limiting device is provided. The main features of the scheme are: a fundamentally new high-action high-voltage explosive switcher with a high restoring voltage of more than 500 kV; high-voltage fusible switches that allow limiting overvoltage in the event of a sudden circuit break in the explosive switcher; a

non-inductive resistor with a high thermal capacity and a pulse reactor with operating time of not more than 10 seconds. A series of experimental investigations was carried out, including with the use of current from shock generators to confirm the functionality and technical characteristics of the FCL-220. They showed the effectiveness of the FCL-220 and were sufficient to make a decision on its installation on an existing substation on the busbar connection with voltage of 220 kV. Currently, the FCL-220 is fully assembled and ready for testing in power grid with following pilot operation. The FCL-220 satisfies all the requirements for high-voltage devices and can become one of the key components of power grid security in the future.

### A3-108 Studying the characteristics of non-traditional current and voltage converters for digital substations

А.А. ЯБЛОКОВ, В.Д. ЛЕБЕДЕВ, Г.А. ФИЛАТОВА, С.Н. ЛИТВИНОВ, Е.Е. ГОТОВКИНА, Н.В. ЛЕБЕДЕВА - *Россия*

At present innovative development of electric power industry is aimed at creating a Smart Grid which should have such properties as reliability, flexibility, visibility, self-diagnostics, etc. One of the key technological aspect of the smart grid is measuring instruments and devices. The development of microprocessor technology opens door for the possibility of using new (nonconventional, low-power) current and voltage converters that were not previously used in power industry and have advantages over electromagnetic current and voltage transformers (no effects of saturation and residual magnetization of magnetic circuits, as well as ferroresonance phenomena, explosion and fire safety, low weight and size indicators). Such converters include the Rogowski coil, shunt, galvanomagnetic sensors, resistive divider and others. However, the operation of these converters under actual conditions (strong electromagnetic fields, wide temperature range), as well as their joint work with secondary devices, especially with intelligent measuring devices, requires further research. It is worth noting that IEC 60044-8 does not include the requirements to non-conventional instrument converters.

The article will present the results of studies of transient, frequency, thermal and other characteristics of various non- conventional current and voltage converters (including digital transformers), as well as the results of tests of their collaboration with electric power meters and relay protection and automation devices. It will focus on the influence of the electromagnetic fields on the currents and voltages measurement errors using the non-conventional primary converters.

Similarly, the report will review and analyze the characteristics of a transformer with magnetic conductors of electrical and amorphous steel, galvanomagnetic sensors, shunt and resistive voltage divider. The report will also present the results of trial operation of digital transformers with non-conventional primary converters at substations in the central and northern parts of the Russia.

### A3-109 Power plants Modernization by Smart integrated vacuum generator breaker switchgears

K. VENNA, H. URBANEK, F. RADEMACHER - *Дания*, J. ROMÁN, I. CÁRCAMO, G. URQUIZA - *Испания*

New grid scenario requires conventional power plants to be more flexible and reliable to adapt to the inclusion of renewable energies into existing networks. This is mainly due to the fact that such resources are only partially predictable in advance and non-influenceable. This lead to higher number of switching operations and faster response of existing conventional plants in connection to the grid.

This paper presents a proposal about how an old conventional power plant can be modernized to handle today’s dynamic digital grid scenario with focus on:

- Numerous switching operations, for a flexible demand;
- New operation modes, being able to work in island mode, storing energy;
- High demands in terms of reliability, equipment protection against faults;
- Personnel safety with target zero accidents;
- Reduction of life cycle costs and autonomy in maintenance;
- Climate change impact and reduction of greenhouse effect gas emissions;

The purpose of this paper is to explain how latest achievements in electrical equipment and

digitalization concepts developed by manufacturers can allow existing conventional power plant to be modernized up to date for today's energy generation challenges.
A typical case study is used to describe a smart generator switchgear with highly integrated and digitalized design and interaction between different plant equipments is analysed to achieve an overall electrical balance of plant.

**A3-110 Development and Electrical Performance Research of a 12kV C4F7N/CO2 Ring Main Unit**

Z. LI, E. DONG, R. ZHANG, Z. ZHANG, Y. WANG, X. YAN, Y. Z, D. AN, H. HUANG, X. Xu - *Китай*

The mixtures of C4F7N (fluoro-nitrile, C4 for short) and CO2 has good insulation performance and low greenhouse effect, considered a potential replacement gas of SF6. SF6 ring main unit (RMU) with widely applicate requires gas insulation and arc extinguishing performance.
The development of C4/CO2 mixtures RMU has high engineering application and environmental protection value. In this paper 12kV C4/CO2 load switch RMU with metal plate to extinguish arc was designed using C4/CO2 instead of SF6. The RMU passed the withstand voltage test of 1.2 times the rated insulation level at 6% mixing ratio and zero gauge pressure which means the insulation performance of C4/CO2 is excellent. The research on active load current breaking performance was on a synthetic test circuit. By measuring the arc volt-ampere characteristics and observing the arc moving images, it was found that compared with SF6 arc in C4/CO2 has a lower voltage, wider arc channel and more liable to fall from the metal plate. Therefore, the arc extinguishing structure needs to be optimized.
The influence factors of breaking capacity are studied and optimized design is carried out. A small increase in low pressure has no help and Increasing gas mixing ratio can obviously enhance the breaking capacity. Therefore, the pressure is 0.14MPa, and the mixing ratio is 15-20%.Switch opening speed should be make sure moving contacts out of the arc extinguishing plate when the arc is extinguished. Therefore, the switch opening speed is improved to 6.5m/s. In the design of different arc extinguishing plate structures (flat plate with and without insulation cover structure, sparse flat plate with insulation cover structure and curved plate without insulation cover structure), the flat plate with insulation cover structure has the best breaking performance when the plate spacing is 3mm. A optimized structure was used to avoid arc drop and CuW contact was added on the static contact and moving contact to improve the anti-ablation ability.The improved C4/CO2 RMU successfully passed active load current opening and closing tests of 630A for 10 times and of 1000A for twice. The research shows C4/CO2 can meet the breaking requirements and achieve the purpose of replacing SF6.

**A3-111 Experience of Capacitive Current Switching of EHV and UHV AC Circuit Breaker in Power System and Test**

G. LI, S. L. YAO, C. H. ZHANG, P. R. WANG, D. F. YAN - *Китай*

Capacitive current switching is the basic operation for high-voltage AC circuit-breaker in power system, and it is easy for circuit-breaker to clear capacitive current which is usually only a few hundred amperes. However, the circuit-breaker is at risk of restrike when switching capacitive current. Restrike may cause undesired overvoltage or high frequency transient process, which may affect the power quality of the grid. Restrike may cause damage to circuit-breaker and other electrical equipment. Therefore, capacitive current switching performance is important for high-voltage circuit-breaker and must be verified strictly.
Restrike is probabilistic in the process of capacitive current breaking, it is related to the characteristics of circuit-breaker and power grid. The probability of restrike cannot be eliminated. In order to evaluate the possibility of restrike, the capacitive current switching test is specified in standards to simulate the most severe operating condition in the system.
With the development of China's AC and DC UHV transmission projects, UHV and EHV circuit-breakers have been widely used in China, and there are more and more system conditions and test requirements for capacitive current switching of UHV and EHV AC circuit-breakers, especially for circuit-breakers which are used to switch filter bank in UHV convertor station.
In the face of more and more new system conditions, such as UHV back-to-back capacitor bank switching and filter bank switching, we have found that the UHV and EHV circuit-breakers that have passed the type tests specified in the current standards have encountered many problems when

switching capacitive current in actual system. This means that the current standards and test methods have not been adapted to the new working conditions, and it has been impossible to effectively evaluate the reliability of capacitive current switching of UHV and EHV circuit-breaker. The standards and test methods related to capacitive current switching test need to be improved according to the actual situation.
In recent years, a large number of capacitive current switching tests for UHV and EHV circuit-breakers have been performed in China. In order to improve the reliability of capacitive current switching of UHV and EHV AC circuit-breakers, this paper studied and analyzed these typical problems, discussed the defects of the current relevant standards and test methods, put forward the ideas for perfecting the current standards and test methods. At present, China is developing the corresponding standards for circuit-breakers used for filter banks. This paper introduced the idea of standard setting and the test scheme for circuit-breakers used for filter banks, and finally introduced the actual tests of UHV and EHV circuit-breakers.

**A3-112 Basic aspects of switching with series-connected vacuum interrupter units in high-voltage metal-enclosed and live tank arrangements**

J. TEICHMANN, R HUTH, T. GOEBELS, J. WEISKER, P. G. NICOLIC - *Дания*

Vacuum switching technology combined with CleanAir insulation yields a highly performant, environmentally benign and maintenance free solution, replacing SF6 in high-voltage switchgear. For rated voltages up to Ur = 245 kV (Ur = 170 kV already available at the market) single break vacuum interrupter units are under development. One option to enable the vacuum switching technology combined with CleanAir as insulation medium at rated voltages up to Ur = 550 kV and beyond is the use of series-connected vacuum interrupter units as circuit breaker. This principle can e.g. be used for metal-enclosed and live tank circuit breakers. The main challenge for the application of series-connected vacuum interrupter units is the voltage distribution across the series connection during switching operations and in open position. Due to parasitic capacitances, the voltage is not distributed equally across all series-connected vacuum interrupter units. In metal-enclosed circuit breakers, the line to ground capacitance is higher than in live tank breakers and consequently the voltage distribution across the switching units is more asymmetric. For balancing the voltage distribution, capacitors can be connected in parallel with the interrupter units for the purpose of grading. These aspects are considered in this study by means of a laboratory prototype with a series connection of two medium-voltage vacuum interrupter units and in a second laboratory setup, live tank supported vacuum interrupters in series connection are being investigated. High-voltage tests as well as high-power breaking tests have successfully been performed on 145 kV 40 kA vacuum interrupters. An outlook on the application of series-connected vacuum interrupter units at highest voltage levels is given.

**A3-113 Interrupting Performance Evaluation of High-Voltage Gas Circuit Breakers Using CFD Simulation and Data Analysis Technique**

J. H. PARK, S. Y. WOO, H. K KIM, M. J. HA, K. B. SEO - *Корея*

This paper presents the analysis method of the interrupting performance of high-voltage gas circuit breakers (GCB). From the computational fluid dynamics (CFD) and electric field analysis, electric field intensity and flow field variables such as gas pressure, density, and temperature are obtained. Using the data analysis technique, we investigated the important factors which have considerable effects on the decision of pass or fail of high power laboratory testing. Then, through the optimization method, the optimal weighting value for each factor is determined. We investigated major interrupting duties including L90, T100a/s, and T30 duties for SF6 GCB. For each duty, due to different interrupting current and transient recovery voltage (TRV), the interrupting performance index is different.
For puffer type SF6 GCB, pressure rise and flow rate from compression volume to the arc region are important to cool down the arc quickly. For self-blast type GCB, high pressure rise and low temperature gas flow at the heating channel are major factors to achieve successful L90 interruption. In the case of T100a/s duty, E/rho (electric field intensity over gas density) is a good indicator that represents the dielectric recovery characteristics. Regarding T30 duty, from our

simulation results, success or failure can be distinguished from the direct comparison of gas temperature in front of the pin electrode.
For SF6-free GCB, we investigated the puffer type GCB filled with 5% Fluoronitrile and 95% CO2 mixture gas. L90 duty of SF6-free GCB is most difficult to pass because of the lower arc cooling power compared to SF6 gas GCB. Through the data analysis technique, it is found that the pressure ratio of compression volume to stagnation point is important for L90 interruption to a model GCB.

### A3-114 The First Development of SF6-free 170 kV 50 kA 60 Hz GIS with Fluoronitile (C4F7N) Mixtures

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Short line faults with 60Hz power frequency for example are quite difficult to interrupt and simulations helped to select the right prototypes. Building strong numerical tools is key to ensure the development of new technology equipment, and a fluoronitrile mixture showed very good compatibility with SF6 tools, methodology and criteria. Dedicated mock-up for simulations allowed to capitalize and not only to propose the first SF6-free 170kV 50kA 60Hz GIS circuit-breaker, but also to accelerate the development of a full range of SF6-free alternative solutions to the customers. Using these simulation tools, the circuit-breaker was designed and demonstrated its full short-circuit breaking performance: terminal faults and short-line faults with respectively 10%-100% and 75%-90% of the short-circuit current. Out of phase and capacitive current switching were also successfully passed according to the IEC standards.
In addition, all GIS test results by IEC standard which are relevant to a fluoronitrile mixture of fluoronitrile (C4F7N), carbon dioxide (CO2) and oxygen (O2) are introduced in this paper. GIS design basis came from SF6 one but the most of inside part details have been changed due to different gas properties comparing to those of SF6. However, external dimension has been kept the same for enclosure dimension and eventually the same foot-print as SF6 GIS. This makes installation and replacement easy in utility point of view.
The fluoronitrile mixture has been successfully investigated for all required performances of this new ratings GIS. It is considered to be the first development of 170kV 50kA 60Hz GIS with SF6-free solution and the most probable solution to replace SF6 so far.

### A3-115 Case Study – Improving Reliability of Circuit Breaker by using Controlled Switching and removing Pre Insertion Resistor (PIR)

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Over-voltages are produced during routine switching operations and unscheduled opening operations aimed at interrupting a short-circuit current in power systems. Switching On/Off of Transmission Lines by Circuit Breaker operation leads to generation of Switching Over-Voltages due to sudden change in configuration of electrical Transmission network. Over-Voltages during the closing operation are entirely random and may depend on the CB pole mechanical scatter and point of closing in the source voltage wave. Limiting these Switching Over-Voltages are extremely crucial especially in Transmission network with rated voltage of 400kV or above as Switching Impulse Withstand Voltage level in these High Voltage network may between 2.0 – 3.0 p.u. or even more . The switching over-voltages are more pronounced during the operation of long transmission lines due to the high capacitance of the very long lines.
In order to mitigate Switching Over-Voltages during Line Switching, most common technique is to provide Pre Insertion Resistors (PIRs) in Circuit Breakers. However, addition of this extra component i.e Pre Insertion Resistors impacts the overall reliability of Circuit Breakers due to problem arising in linkages/levers and subsequent stucking of Pre Insertion Resistors, SF6 Leakage through Pre Insertion Resistors joints etc. These issues associated with Pre Insertion Resistors have led to development of an alternative method that can be used for mitigating Switching Over-Voltages i.e. Controlled Switching of Transmission Lines using Controlled Switching Device (CSD). In this method, Mechanical Closing/Opening of Circuit Breakers are controlled to an optimal instant by introduction of a suitable time delay through an electronic device called as Controlled Switching Device (CSD). Benefits of Controlled Switching in Transmission Lines are more pronounced incase of re-closing than normal closing as trapped charges presence during re-

closing may lead to very high switching over-voltages. In addition to Controlled Closing/Re-Closing, Controlled Opening of Transmission Line reduces the probability of forced outages of Circuit Breaker due to electrical failures as Controlled Opening eliminates risk of re-strikes. Implementation of Controlled Switching technique for Transmission Line must take into account configuration of Transmission Line :
- Uncompensated Transmission Line
- Shunt Compensated Transmission Line

In this paper, a 400kV (340 km long) Transmission Line provided with shunt compensation was switched through both techniques i.e. Circuit Breaker with Pre Insertion Resistors & Controlled Switching Device and In-rush current & Over-Voltages observed during switching were measured. Results for both cases are presented in this paper.
All the retro-fitments made in substation connecting aforesaid 400kV Line like Installation of Controlled Switching Device (CSD) to switch Line from one end, Installation of sensors to provide feedback of Line side Voltage to CSD etc are discussed in the paper. In addition to this, philosophy considered in Controlled Switching of Line to mitigate Switch Over- Voltages and Inrush current has also been highlighted in this paper. The long term objective of this exercise is to compare switching over voltages generated in long transmission using CSD & PIR.

## A3-116 Innovative SF6 Free Load Break Switch with Shunt Vacuum Interruption (SVI) Technology

**C. PREVE, R. MALADEN, D. PICCOZ –** ***Франция,***

Thanks to its exceptional physical properties, SF6 is widely used as dielectric and quenching gas in medium voltage switchgear since the seventies. However, it presents the disadvantage to have the highest global warming potential among any other industrial gas (GWP = 23 500), and a life time upper than 750 years which means that concentration level in the atmosphere will increase over time. For this reason, alternative solutions must be found.
This paper presents an innovative and compact SF6 free medium voltage load break switch with shunt vacuum interruption (SVI) technology applied to secondary distribution.
Vacuum interrupter is a well-known, mastered and effective technology to ensure current breaking in medium voltage (MV) switchgear. It is broadly used for MV circuit-breakers.
In order to make a load break switch with vacuum interrupters, the traditional solutions consist in setting vacuum interrupters in series with a disconnector. In this case, 2 different mechanisms are required: one for the vacuum interrupter, one for the disconnector. The vacuum interrupters must be able to make and break the load current, withstand and make the short-circuit current with its peak value. This architecture presents strong drawbacks: the manner to operate is different than the current 3-positions SF6 switch and is very expensive.
To solve these issues, an innovative solution with vacuum interrupters set in parallel of the main circuit has been developed. In this design, the vacuum interrupters are only used during the short period of the breaking phase. In this case, the vacuum interrupters do not require a dedicated driving mechanism and have only to be able to break the load current. Consequently, they do not need to withstand and make the short-circuit current (and its peak value). Moreover, this solution presents the benefit to reduce the temperature rise because the load current is not passing through the vacuum interrupter when the switch is closed. Disconnection is ensured by an air gap and earthing is done using a third contact. The operating mode is the same as current SF6 3-positions switches. Breaking and disconnecting are done in one operation and earthing in a second operation. Both are performed with the same operating mechanism similar to those used in SF6 3-positions switches for years. The dielectric insulation is ensured by pure air at different pressures depending on voltage rating. As example, for 12 kV switchgear, the pressure is 1,4 bar absolute whereas for 24 kV, the pressure is 2,5 bar absolute. By increasing the pressure compared to SF6, it is possible to keep the same dimensions and footprint.
Based on this technology, complete ranges of Secondary Air Insulated Switchgear (AIS) and Gas Insulated Switchgear (GIS) have been developed. They present the advantages to be fully environmentally friendly, compact, safe for people, easy to operate and cost effective. In addition, the use of pure air does not affect the minimum operating temperature and does not require specific precaution at end of life. The dimensions of Secondary AIS and GIS are the same as SF6 ones and

the switchgear is also fully interchangeable with current SF6 switchgear. Pilot switchboards at 12 kV and 24 kV have already been installed on the field. This technology is fully validated according to IEC standards and enables to reach all the performances required for Secondary MV application. For Primary GIS, the same principle of pure air at different pressures depending on voltage has been applied in order to keep the same dimensions as SF6 switchgear. Primary GIS functions are circuit- breakers and already based on vacuum interrupters. Then, this technology will be re-used for pure air Primary GIS.

**A3-117 Return of experience of the SF6-free solution by the use of fluoronitrile gas mixture and progress on coverage of full range of transmission equipment**

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Since 2014 with the first disclosure at CIGRE of an eco-friendly alternative to SF6 by using Fluoronitrile compound (C4F7N) mixed with CO2 and O2, this gas mixture has been implemented on several projects covering ambient temperatures from -30°C to +50°C. The gas mixture is used now in Gas Insulated Switchgear (GIS), Gas Insulated Lines (GIL) and Air Insulated Instrument Transformer (ITR). Thanks to the gas mixture properties (high dielectric strength and strong switching capabilities), the design and manufacturing of high voltage products are available with comparable dimensions and ratings than up to date SF6 equipment. In all these products proven in the field, the gas mixture based on C4F7N reduces the CO2 equivalent by more than 99% compared to SF6.

Field experience has now been gained for more than 3 years with positive feedback from users and a strong expansion of the installed base is ongoing in the transmission equipment domain, as presented in this paper.

Recent developments have shown the scalability potential of this SF6-free technology from 72,5kV up to 550kV with associated rated short circuit current ranging from 31.5kA up to 63kA ensuring compactness and reliability.

This paper presents the studies that have been done on the gas mixture optimization in order to increase the current interrupting capability up to 63 kA 60 Hz while limiting the number of gas mixtures to cover all applications. The impact of the Oxygen (O2) ratio on the breaking performance and on the dielectric strength is summarized. As the C4F7N content on the gas mixture should be limited for outdoor applications up to -30°C, the minimum C4F7N ratio is identified to ensure insulation in the worst switchgear lifetime conditions.

Two optimum technical and economical gas mixtures are now selected to cover the full High Voltage range under development:

• 5% mol C4F7N / 13% mol O2 / 82% mol CO2 for -25°C application,
• 3.5%mol C4F7N / 13%mol O2 / 83.5%mol CO2 for -30°C application.

**A3-118 C5 fluoroketone based gas mixtures as current interrupting media in high voltage switchgear**

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The high global warming potential of SF6 has led high voltage switchgear manufacturers to seek possible alternatives to this highly effective dielectric insulation and current interruption medium. Several alternatives to SF6 have been investigated, including synthetic air and CO2. While these two gases have the advantage of negligible greenhouse warming potential (GWP) compared to SF6, their dielectric strength and current interruption capability are below those of SF6 (when comparing similar gas densities and flow conditions). To compensate for the reduced dielectric strength, equipment with larger dimensions and higher filling pressures than is used with SF6 can be employed to achieve the same voltage rating. Similarly, the short-circuit current rating can be reduced to compensate for the reduced current interruption capability.

Another approach to the design of electrical equipment that permits increasing the inherent dielectric strength of an insulating medium based on synthetic air or CO2 is to add a relatively small amount of a gas with a high GWP and high dielectric strength, analogous to mixtures of SF6 and

N2. To avoid condensation above a certain temperature, the partial pressure of C4 fluoronitrile used in electrical equipment must not exceed a certain threshold.
Gases with negligible GWP (compared to SF6), but high dielectric strength, such as CF3I and C5F10O (C5 fluoroketone), have also been considered. While concerns regarding the toxicity of CF3I itself and the toxicity and conductivity of its decomposition products (such as I2) renders difficult its application in electrical equipment, C5 fluoroketone does not have this disadvantage. In fact, C5 fluoroketone is a molecule that has a high dielectric strength, is not classified as toxic, has a GWP < 1, has no ozone depletion potential, and is compatible with the materials used to construct electrical equipment. As in the case of C4 fluoronitrile, the amount of C5 fluoroketone that can be used in electrical equipment is limited by the need to avoid condensation above a certain temperature.
In this work the current interruption performance of mixtures that include C5 fluoroketone and use nitrogen and oxygen or carbon dioxide and oxygen as the background gas has discussed. Authors focus on aspects of current interruption performance that can be influenced by small design changes (with respect to a design optimized for use with SF6). Two examples of such design changes for very two different applications are given:
1) Modifications to a make-proof earthing switch that permit it to achieve the same induced current switching ratings possible with SF6.
2) The valve design modification of a circuit breaker to improve the performance in different short-circuit current test duties, and results of computational fluid dynamics studies that allow these improvements to be quantified and understood.

**A3-119 Theoretical and Practical Behaviour of Ecofriendly SF6 Alternatives in High Voltage Switchgear**

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In the last ten years the advancement of SF6-free HV equipment has seen an increase in production from the manufacturers and acceptance from the utilities. Yet many important questions remain open today and addressed in different ways. Three main new gaseous technologies of non-SF6 equipment are being considered. All using CO2 as carrier gas, namely, pure CO2 switchgear and CO2-based switchgear plus 3M™ Novec™ 4710 Insulating Gas (Fluoronitriles, C4F7N) or 3M™ Novec™ 5110 Insulating Gas (Fluoroketones, C5F10O) as additives.
Different aspects on the dielectric and thermal interruption regimes have been discussed in different works. Still the operational aspects, i.e. the behaviour of the new eco-gas mixtures with regards to their gas lifetime -and composition- during operation are not fully addressed. In expert committees it is discussed whether standard type testing covers all possible real-life scenarios. It is necessary to understand and explore through R&D testing these scenarios, to facilitate a better design or retrofitting of existing equipment.
Diving into the thermodynamics of the alternatives, the thermal decomposition of Fluoronitriles (FNs) and Fluoroketones (FKs) occur at temperatures exceeding 800 °C. During interruption, the occurring chemical reactions create several gaseous radicals and by-products. These are decomposed further with the changing temperature fields and recombined to several stable gas components when the temperature decreases. In order to understand the impact of this, two models of the thermal decomposition of these gas mixtures is presented. The different reaction stages are subdivided in time and mapped to the interruption process that of a high voltage circuit breaker (HVCB) to judge their influence.
Through testing and gas analysis the decomposition rate of CO2+C4F7N mixtures is derived and estimations on gas lifetime presented.
The results of this work contribute to answer the question of the real environmental benefit that the different alternatives have. It is not only about the Global Warming Potential (GWP) or Ozone Depletion Potential (ODP). Neither is only a matter of size or footprint horizontal nor vertical, or the minimum operating temperature possibilities, or the scalability to higher voltage ratings, etc. Is about all the above and several more characteristics. Looking only at one or two convenient environmental parameters is rather narrow-minded and borderline greenwashing.
This work presents considerations based on simulations, calculations, R&D testing and laboratory

analyses. Its results enable utilities and users of SF6-alternative switchgear to take a more informed decision with regards to their assets.

**Предпочтительная тема 2. Управление сроком службы оборудования для передачи и распределения электроэнергии**

### A3-201 CIGRE Reliability Survey on Equipment

Hiroki ITO, Nenad UZELAC, Frank RICHTER, Robert le ROUX, Wayne PEPPER, Li PENG, Anongpun MAN-IM, Ioan HATEGAN – *om SC A3 CIGRE*

Reliability of substation equipment in power systems is of major concern especially for transmission and distribution system operators and asset owners. A major failure of substation equipment may result in significant system outages with the associated power restoration efforts as well as possible safety implications. There are also financial implications in case of poor reliability. In addition to the cost of a system outage and its restoration, poor reliability will contribute to higher system operating and maintenance costs to the operators and, ultimately, their customers. For these reasons, CIGRE periodically conducts an international reliability survey on equipment in power systems that can provide good feedback on the validity of international standards. The first reliability survey was carried out in 1974-77 and covered nearly 78,000 circuit breaker years in service. The results were published in 1981 and had a significant impact on testing requirements in IEC standards. In the second reliability survey, data were collected for the period 1988-91 and almost the same number of circuit breaker years was sampled, but the survey was limited to circuit breaker single pressure SF6 technology. CIGRE Technical Brochure (TB) 083 remains a valuable source of information for the circuit breaker community. Later, the CIGRE TB 165 provides further considerations on lifetime management of circuit breakers. The reliability data related to GIS were also collected in 1990 (first survey) and in 1996 (second survey).
The third reliability survey included not only circuit breakers but also disconnecting switches, earthing switches, instrument transformers and gas insulated switchgear (GIS). The time period covered was 2004-2007, and the enquiry covered equipment with voltage ratings higher than or equal to 60 kV. The results from the circuit breaker part and GIS part were presented in CIGRE Technical Brochures 510 and 514, respectively. Only single pressure SF6 circuit breaker technology was included in the third survey. A fourth reliability survey on substation equipment is under progress and intended to expand the scope to cover generator circuit breakers, vacuum circuit breakers, and surge arresters, in addition to SF6 circuit breakers, disconnecting switches, earthing switches, instrument transformers and GIS only focusing on major failures. The paper will present preliminary results of the fourth survey and compare them with the previous results.

### A3-202 Operational Experience, Field Test and EMT Simulation for EHV ShuntReactor Switching

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Statnett commissioned 25 new shunt reactors in the Norwegian 300- and 420-kV EHV systems over the past 16 years and installs only VSRs since 2009. The original idea for using VSRs, rather than conventional shunt reactors, was to reduce transients in weak alternative current (AC) systems since a variable shunt reactor (VSR) can be energised and de-energised at a high tap, hence low reactive load. Additional VSR benefits were discovered later such as using a VSR as part of the reactive-power control for the high voltage direct current (HVDC)-crowded Kristiansand substation in Norway, simplified spare strategy and built-in adaptation to both long- and short-term variations for the reactive power.
Statnett unfortunately experienced several reactor circuit-breaker (CB) failures, as previously described in [1], and therefore has implemented the following improvements in order to reduce the failure consequences and their probability of occurrence:
• Only composite-housed reactor CBs are allowed, and previously installed porcelain-housed reactor CBs have been replaced.
• An in-house program for on-line monitoring of reactor CBs is under development.
• Controlled-switching devices (CSDs) are programmed to send a control-center alarm when re-ignition occurs, three re-ignitions for the same reactor CB prohibit re-energization.

• Mixed SF6/N2-gas instead of pure SF6-gas is used for low temperature region, it increases the dielectric strength and meanwhile keep the dew point below −40˚C.
Statnett's commissioning method for new reactor CBs follows a standard procedure and includes on-site "fingerprint" measurements, which opening and closing times occasionally differ by at least 1 ms compared to factory routine tests. Both controlled closing and opening are employed and the re-ignition-free arcing window for controlled opening is selected according to the Manufacturer recommendations based on the outcome of type tests at the correct filling pressure.
Recent transient recovery voltage (TRV) field measurements on a 420-kV two-unit self-blast SF6 reactor CB, without grading capacitors, at two filling pressures and varying arcing times are described. The field-measured minimum re-ignition-free arcing times become similar to previous type-test results. Furthermore, electro-magnetic transient (EMT) simulations and calculations agree well with the field-measured TRV waveforms and show that the load- and supply-side CB units become subjected to approximately 70 % and 30 %, respectively, of the maximum peak TRV across both units**.**

### A3-204 In-service Diagnosis of Grading Capacitor Dielectric Deterioration

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Disruptive dielectric failure of circuit breaker grading capacitors is well known in AIS and GIS transmission switchgear. This paper describes a methodology, initially developed to investigate the cause of damage to interrupter nozzles during reactor CB opening operations, that has proved suitable for grading capacitor Partial Discharge (PD) measurement. A key technology used in the investigation is radiometric PD location which allows identification of the origin of individual PD events from a CB via the reception of RF impulses. During the arcing period of a CB operation, impulses are emitted from the interrupters as the contacts move. However, field tests under CB open operations revealed additional PD impulses were also recorded immediately after the extinction of the current when the grading capacitors were highly stressed. This effect was repeatable over many operations until the defective grading capacitor was replaced. The defect in the grading capacitor was confirmed by testing in a HV laboratory which revealed abnormal results in both Tanδ and IEC60270 PD tests. As a consequence the capacitor was stripped down revealing extensive damage to many of the individual capacitor units within the assembly, confirming that the capacitor was effectively at its end of life. Analysis of the PD data recorded during the investigation demonstrated that the duration and intensity of the PD increased over a period of 78 days involving 14 separate CB open operation measurements. One particular PD metric, based on assessing the number of emitted PD impulses that exceeded an amplitude of 0.1V, indicates that the remaining life of this capacitor to be ~25 operations after the amplitude threshold was exceeded. A significant benefit of this measurement approach is that the CB remains in service during testing.

### A3-205 Circuit Breaker De-Rating Assessment under High DC Time Constant

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High-voltage circuit-breakers standards such as IEC 62271-100:2008 define a default value of DC time constant deemed adequate for most applications but "special cases time constants" concept is introduced for those situations when it is insufficient. There is in general limited availability of references in applying de-rating assessments under high DC time constant and this paper is intended to fill that gap by providing a comparison of available assessment approaches. The paper provides a compact literature review of the subject matter before moving into comparative de-rating assessment methodology with clear recommendations on the benefits for those seeking to assess potential equipment overstresses without the benefit of specific equipment test performance.
In particular, the paper covers the following asymmetrical short-circuit current breaking duty de-rating assessment methods:
• accurate calculation of arc energy in the last major current loop prior to interruption assuming constant arc voltage or constant arc resistance;
• simplified methodology described in CIGRE Technical Brochure 304 and based on the product of the peak or square of the peak and duration of the last major current loop before interruption (implicit in these approaches is the assumption that arc voltage or arc resistance is constant during the arcing period respectively);

• ENA Engineering Report 89.
A multi-criteria matrix comparing the strengths and weaknesses of each of the above assessment methods is presented and covers the safety aspects, ease of use and how wide it is used internationally.

**A3-206 Actual use survey and maintenance practice of circuit breakers for frequent switching applications**

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The number of switching operations is one of the key factors to determine the electrical and mechanical wear of a circuit breaker. A high-voltage circuit breaker is normally in service for more than 20 years after installation. Its wear due to accumulation of current switching operations while in service may result in major or minor failures. CIGRE TB510 reports that frequent operation
duty breakers such as shunt reactor or capacitor bank applications have a higher failure rate compared to other application such as feeder or busbar connections.
This paper shows the lifetime and maintenance cycle tendency of frequently operated breakers, and examples of maintenance activities as provided by utilities and manufacturers. 468 breakers with rated voltages of 72 kV to 300 kV which were in service in 2018 at three Japanese utilities were investigated.
The result shows realistic usage conditions for shunt reactor and capacitor bank applications. Usage life is about 40 years and the number of operations is less than 2,000 for most of the breakers. Breakers which were maintained properly exceeded 10,000 operations although they were in other applications. The survey result is helpful to set up guidelines for inspection plans. The maintenance program, parts of circuit breaker and application are also improved to maintain reliability. Rationalization is required to TBM so that CBM becomes more important. Various kinds of activities to extend the life and to improve the reliability are applied for breaker itself and system operation.

**A3-207 A campaign for the ageing evaluation of station hollow core composite insulators after a number of years of service**

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The reliability of electric transmission network is strictly related on the quality and material reliability of its electrical equipment. Insulators play a role of paramount importance for the reliability of the grid. Silicon rubber hollow core insulators are being widely used replacing porcelain thanks to the advantages as pollution insulation withstand, safety and reduced life cycle cost.
The environmental conditions combined with the electric field, may result in the insulator ageing depending on the design, technology and silicone compound formulation/quality.
A standard monitoring or field-testing method for early detection would be helpful for life prediction and in the worst case to replace the equipment before failure.
This paper is a common approach of a manufacturer of High Temperature Vulcanized (HTV) silicone rubber (and Liquid Silicone Rubber (LSR) as well) Hollow Core Insulators (HCI) and a Transmission System Operator (TSO) to combine an experience of 30 years with HTV silicone rubber HCI.
The Italian TSO TERNA has been an early precursor of the use of composite insulators in the HV Equipment specifying silicone composite insulators for the housing of high voltage Current Transformers (CT) for the 170, 245 and 420 kV classes replacing porcelain for safety reason and aiming to a better behaviour in high contaminated area without incur in insulator washing anymore. This paper resumes the experience on technical evaluation of HTV silicone rubber HCI with same technology and base silicone polymer but different shed profiles over periods up to 30 years to evaluate ageing behaviour in harsh environments.
Reinhausen Power Composite and TERNA based on such very long joint experience decided to start a campaign for the ageing evaluation selecting a number of sites falling between heavy and very heavy site pollution severity where Reinhausen Power Composite HTV HCI are installed in

the Italian high voltage grid and defining a number of non-destructive tests in order to get as much as possible information on the ageing. Such campaign refers to HTV HCI with homogeneous insulator characteristics installed on CTs over a period of more than 15 years of operation on the 420 kV grid.

### A3-208 Overvoltages research in switching modes of cable and mixed overhead-cable lines, power transformers, shunt reactors and capacitor banks of 110-750 kV and development of a controlled switching device for the above electrical equipment

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Switching of electrical equipment can be accompanied by unacceptably high overvoltages, throws of switched currents which are comparable in magnitude with short-circuit currents, and the appearance of aperiodic components in the switched current with parameters (magnitude and duration) exceeding the breaking possibilities of switching equipment.
Despite the short duration, overvoltages are characterized by a high ratio to the operating voltage and can be dangerous for both the main electrical equipment and secondary circuits.
The presence of an aperiodic component in the breaking current can lead to the impossibility of interrupting such a current during the operation of the circuit breaker (CB) delaying the breaking process and, as a consequence, to a severe emergency of the circuit breaker.
Methods and means of controlled switching of power equipment, non-reacted and reacted power lines, shunt reactors, capacitor banks and power transformers have been widely introduced in the world energy sector over the last years. The basic principle of controlled switching device (CSD) when receiving a command to perform a switching operation is to delay the signal for CB control circuits so that the specified (required) contact switching moment (or pre-arc) relative to the voltage or current angle is provided.
For the last 14 years CIGRE WG A3.07 issued a number of basic documents concerning the mentioned subject, and also new CIGRE WG A3.35 taking into account developments of WG A3.07 prepared the application of the controlled switching in a world practice extensive review “Guidelines and best practices for the commissioning and operation of controlled switching projects. Reference: 757. February 2019”.
Research works carried out in Russia on the study of overvoltages research in switching modes of cable and mixed overhead-cable lines, power transformers, shunt reactors and capacitor banks of 110-750 kV as well as the use of controlled switching world experience analysis, allowed to begin development of domestic CSD and offer a number of new technical solutions for the power industry of the Russian Federation.

### A3-209 X-ray inspection of operating high-voltage oil-filled circuit breakers

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This article presents the results of the studies of non-destructive X-ray testing method capabilities of high-voltage oil-filled equipment based on VMT-110 minimum oil circuit breaker with porcelain external insulation. The main advantage of the examined method is the possibility of efficient non-destructive testing of internal elements of high-voltage oil-filled equipment located at the installation site without its dismantling. An instrumentation and analytical system (IAS) based on monoblock X-ray unit with direct-current tube voltage and directed radiation output is suggested for X-ray inspection of high-voltage oil-filled equipment.
After the analysis of possible reasons for failures of VMT-110 circuit breakers during their operation a list of specific defects and Special Defective Sample (SDS) were created for laboratory studies. The results of SDS examinations showed that this technical solution allows to reveal at least 75% of specific types of defects in internal structural elements of minimum oil circuit breaker. The assessment of the method informativeness was carried out for inspection of high-voltage equipment technical condition. The resolution of X-ray image of the equipment is not worse than 1 mm of its original size.
Suggested radiographic system and control technology have been tested at four operating 110 kV voltage class substations.

**A3-210 Online monitoring of paper-oil insulated current transformers**

I. AYERDI, I. HUERTA, J. MENDIZABAL, J.M. NOGUEIRAS - *Испания*

Asset management is becoming a key task in electrical networks, with the objectives of improving the quality of service, enhancing the safety of staff and installations, and boosting the economic performance of the system.

Smart electrical networks, with the incorporation of modern monitoring technologies and communication systems, will make possible a more efficient management of generation, transport and distribution of electricity. The integration of monitoring systems will allow the condition assessment of the network primary equipment, providing an essential tool to minimize failures and improve security of supply.

The rapid evolution of information and communication technologies together with an increasing availability of sensing components, have already led to the first on-line monitoring systems; however, they have been oriented preferably to power transformers, while the diagnosis of paper-oil insulated instrument transformers is still performed by means of the conventional periodic off-line testing of the de-energized equipment.

This article describes the first phase in the development of an on-line monitoring system for paper-oil insulated instrument transformers, consisting of three sensors (temperature, pressure and hydrogen dissolved in the oil), together with the conditioning electronics and the communications. The measurement of pressure, temperature and hydrogen allows the detection of anomalies in the operation of instrument transformers, but it is also necessary to design and carry out a series of validation tests that define good and fault conditions, and subsequently analyze together the data obtained by the three sensors in these conditions, to correctly interpret all data.

**A3-211 Influence of Contact Heating on Main Circuit Resistance Measurement and Dynamic Contact Resistance Measurement in High Voltage Circuit Breakers**

T. CHENG, W. GAO, L. JI – *Китай*

Main circuit resistance measurement and dynamic contact resistance measurement (DRM) are electric resistance measurement, and they are effective techniques to evaluate the contact condition of high-voltage circuit breakers in substations without dismantling the breakers. However, metallic fluorides produced during the arc quenching process mask the actual resistance of the breakers. Performing contact heating tests before main circuit resistance measurement can help relieve the influence of metallic fluorides on the static contact resistance Rs. Thus, this paper further studies the influence of contact heating tests on the electric resistance measurement.

A test program composed of 5 subprograms was made to study the influence of contact heating tests, including a) electric resistance measurement tests at the DC injected current (Id) of 750 A without contact heating tests; b) electric resistance measurement tests at Id of 200 A without contact heating tests; c) electric resistance measurement with contact heating tests at the AC heating current (Ich) of 1000 A; d) electric resistance measurement with contact heating tests at Ich of 2000 A; e) electric resistance measurement with contact heating tests at Ich of 3000 A. A new contact system was performed the test program until it was worn out. And Rs of a clean contact system is estimated to study the influence mechanism of the contact heating tests on the electric resistance measurement.

Results indicate that contact heating tests made the metallic fluorides and films fritting and made Rs of the tested contact system close to the one of a clean contact system; contact heating tests had little effect on DRM test results, because the contact movement changed the a-spots formed in contact heating tests, and the new formed a-spots were still influenced by the metallic fluorides and films.

**A3-212 Research on Simulation Testing Method of System Level's Strong Electromagnetic Disturbance in Substations**

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With Ubiquitous Power Internet of Things Technology proposing, its construction will improve the holographic perception of power grid. One of the core technologies of it are Intelligent Sensor and Intelligent Terminal Technology. These sensors, which based on electrical technology, largely distribute in the primary high voltage side. However, these intelligent sensor’s electromagnetic

compatibility experiment standards and interference protection methods are established on the electromagnetic environment of secondary side's cabinet, which is far away from high voltage devices of the primary side. Testing parameters ruled by the standards are not able to fully meet the requirements of actual working conditions. Single parameter's experimental force is below the superposition of multi-parameters' force happen in actual scenes at the same time. Experiments of component level fail to reflect experiments of system level. Thus, the methods and numerical values in the standards are far lower than the complexity and force in the electromagnetic environment of primary high voltage side. It may result in that these intelligent sensor devices, which made up of micro-electronics devices, have high failure rate in the extremely terrible electromagnetic working environment. Even worse, it influences the constructing pace of Ubiquitous Power Internet of Things. For example, electronic transformers still have serious electromagnetic interference problems, although their applications have been spread widely for nearly ten years.
This article firstly analyses the source of typically intense electromagnetic interference in complex electromagnetic environment , and got the transient electromagnetic characteristics of the AIS substations. Then it proposes a system-level electromagnetic compatibility testing method for simulating strong electromagnetic interference process using a circuit breaker turning on and off to control dynamic ball gap discharge to generate dynamic arc. The time of electromagnetic disturbance can be from millisecond to minute, and strong electromagnetic pulse can be generated in 500kHz–2MHz frequency band with controllable intensity. Then the model and simulation are set up for this testing method, and give equivalent comparison analysis of the simulation results and real waveform. Use the electromagnetic interference source testing system built in this paper to do experiments on anti-strong electromagnetic interference capability of electronic transformers of system level. It makes electronic transformers output interference waveforms to verify the validity of the experiment method. The intense electromagnetic interference experimental methods in this article can be used to test electromagnetic compatibility for intelligent sensors in the primary high voltage side in electrical substations. It is able to guarantee the construction of Ubiquitous Power Internet of Things going on smoothly.
The test method proposed in this paper can be used to simulate the complex and strong electromagnetic environment of substations, so as to realize the system-level standardized test of the anti-strong electromagnetic disturbance ability of intelligent devices such as electronic transformers in smart substations and high-voltage primary-side smart sensors in Ubiquitous Power Internet of Things. This method is helpful to ensure the smooth development of smart grid and Ubiquitous Power Internet of Things. Based on the research results of this project, the next step is to study and formulate the relevant test standards for transient strong electromagnetic disturbance in substations, and to promote the application of this test method in a wide range
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### A3-213 Operational Aged Switchgear With The Age Up To 50 Years - Investigations, Testing, Results Considerations For The Design And Operation Of Old and New Switchgear

T. GRÄF, R. SCHILLER - *Германия*

The service life of electrical switchgear is designed for a lifetime of approximately 30 years. Meanwhile, the average operation time of switchgear is significantly higher than 40 years. The main reasons for this are a low susceptibility to failure as well as the compulsion to reduce costs and optimized use. Due to the already high age and the furthermore operation of the electrical infrastructure, the question arises as to whether and how aging effects can be determined after the end of the service life of switchgear that have been operationally aged. For the evaluation of these operational aged switchgear actual efforts within the standardization especially for "maintenance" / maintenance strategies and asset-management should be considered. Investigations were performed at operational aged switchgear after disassembling these at site for examination at the IPH Berlin. Different kinds of investigations and tests showed that there are different "aging" effects influencing the performance of switchgear. The achieved results show that in all of phases of switchgear´s life cycle unfavorable effects influences the ageing process. Even maintenance and service can play a role reducing the lifetime of a switchgear.

### A3-214 Investigation of ferroresonance oscillations in the systems with electromagnetic potential transformers by experimental and calculation methods

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The laboratory research results of ferroresonance in the circuits with inductive voltage transformers 110-330 kV are presented in this report. The researches consist of 2 related stages: experiment and calculations. Main characteristics of voltage transformer, magnetization curve, no-load current and short-circuit inductance were determined at the first stage. After that the approximate mathematical model of voltage transformer was built according the results of known characteristics. The inductive voltage transformer behavior during the switching of circuit breaker with grading capacitors was researched at the second stage.

A huge amount of experiments on switching off the circuit breaker, with variation in capacitance values between the terminals of circuit breaker, ground capacitance, switching angle and secondary load on the transformer allows getting enough information for checking the voltage transformer mathematical model built at the first stage. The model parameters were corrected according the results of experiments on switching off the circuit breaker. The refined model can be used for the research on voltage transformer work in real operating conditions, when the experimental researches are difficult to make, during the modeling of change-over switching on the real substation. The features of voltage transformer mathematical model building are presented in report.

## A3-215 Development of 362kV 63kA 60Hz Self-Blast Breaker without additional capacitors to prevent ferro-resonance by improving the SLF performance

J. H. YOON, J. K. PARK, J. U. CHOI, H. S. AHN, Y. G. KIM - *Корея*

As a result of the continuously increasing demand for electrical energy and grid of high voltage power systems the magnitude of short circuit currents has increased continually. In the range of high short circuit currents increased from 50kA to 63kA with a period of 8 years. The new 362kV 63kA 60Hz GIS has been installed at 345kV KEPCO substation instead of 50kA GIS in KOREA because of the evolution of short circuit currents in recent years. Such high short circuit currents become more difficult to interrupt fault currents. However, reliability of switching of high currents has been more increased in power systems. Specially, one of the most severe failure is short line fault(hereafter refer as SLF) which has been occurring on an overhead transmission line at several hundred meters to a few kilometers away from the circuit breaker terminals. The fault condition is reprsented by a very rapidly rising voltage of Transient Recovery Voltage (hereafter refer as TRV) across the breaker contacts within a very short period after current interruption. The conventional solution to deal with SLF is to install line-to-ground capacitors on one or both sides of the circuit breakers or across the circuit breaker’s contacts to reduce the RRRV. However, in the case the overvoltage occurs in the transformer due to resonance effects. In order to prevent the phenomena during the energizing in the field, needs of circuit breakers without capacitors have been increased. Circuit breakers have been developed to improve efficiency of interrupting performance of short line fault(SLF). This paper provides hot gas flows of self-blast type circuit breaker(CB) without capacitor have been simulated to evaluate interruption performance using CFD. Design parameters such as various types of expansion chamber and nozzles are suggested by using simulation results. Simulated results and experimental ones are compared with previous (ones that of in under development and with capacitor) CB. Modified new shape of an expansion chamber and nozzle has been suggested to improve the efficiency of gas flow and to provide guidelines for designing self-blast breaker with a higher interruption capability.

## A3-216 Damping Performance of VFTO using Magnetic Rings in 800kV GIS

J. W. KIM, J. K SEONG, J. K KIM, K. R KWON, D. J SIM - *Корея*

The very fast transient overvoltage (VFTO) inevitably occurs when the disconnecting switch (DS) of the gas insulated switchgear (GIS) operated. VFTO rises up to 3 pu while travelling in the GIS and creates insulation problems inside or outside of GIS. In the GIS, VFTO generates breakdown between the conductor and the enclosure or sparks outside the enclosure. Outside the GIS, VFTO affects the winding insulation of the transformers and reactors.

Research to reduce the VFTO has been conducted for a long time, and the mitigation methods include applying the shunt resistors, RF resonators, magnetic rings, surge arrester, and making helical slots on the central conductors. Shunt resistor has the best performance but it is expensive

and complicates the DS design. RF resonator changes the resonant frequency but has a problem of insulation breakdown between the resonator and the conductor. Magnetic ring is inexpensive and can be installed around the central conductors. It can be made of ferrite, amorphous, and nanocrystalline materials. Nanocrystalline materials are best suited for VFTO mitigation because of the high impedance at high frequency and negligible losses at the power frequency.
In this study, the VFTO test system was constructed in order to verify the VFTO mitigation performance of the nanocrystalline ring. The test was proceeded according to the insertion loss, the number of the nanocrystalline ring, and the applied input voltage. The test results showed that the VFTO mitigation performance was improved as the insertion loss and the number of the rings are increased and the input voltage is decreased.

### A3-217 Approach & Experience of IoT Based Predictive Maintenance Technologies in Power Distribution Network

H.C. SHARMA, Y. K. GUPTA, S.K. ATRI, P.K. SINGHAL, R.M. BHANAGE, V. K. DIXIT, A. BASU - *Индия*

In this paper we discussed our experiences of adoption of IoT devises for Condition Monitoring of equipment and various methodology adopted for health and life Assessment of equipment. We used modern scientific and technological tools which provide accurate measurement on the condition of the equipment like power transformers and Circuit breakers. The need of the new technological tools used are based on the idea of operating the equipment till the end of its useful life, over and above its design life. This paves way for the performance based management of the asset. Assessment of the condition of the equipment requires adoption of Non-destructive techniques and procedures. The results of the tests performed on the equipment were compared against the manufacturer standards and plotted against the tripping data developed over the years in the company database. The results were interpreted to match the fault data and fault levels of grid stations recorded in the recent past. Using the available knowledge and in conjunction with structured process of data collation and interpretation, the thresholds associated with the features representing the condition of the CB and Power Transformers were determined. The knowledge and understanding of the satisfactory and unsatisfactory condition of the equipment was gained and made explicit from the analysis of remote monitoring of circuit breakers, Infrared Thermography, use of manual ultrasound detection technique, trend data of DGA results for past 3 years, DCRM signatures and trip coil signatures. The paper further demonstrates complete framework related to market availability, deployment and operational experience of IoT based predictive maintenance architecture for switchgear and cable termination. The subject paper present risk model based using a data driven analytics from IT/OT deployed system per se ADMS, SAP and FMEA.
Considering all such parameters critical assets are being identified for application of IoT based predictive model on identified assets. The adopted IoT system aggregate data inputs from installed IED on switchgear and sensors and analyse entire parameter related to electrical, thermal, mechanical & environmental stress related to switchgear and cable termination failure. The design system generates prediction based on data analytics & instantly communicates failure predictions to user for corrective actions. The evolution of various maintenance philosophies are explained in this paper as a case study at TATA POWER-DDL.

### A3-218 Technical-Economic Study on Spark Gaps Replacement by Surge Arresters on Pole-Mounted MV/LV Transformers

W. CHABANE, F.REBBOUH - *Алжир*

Pole-mounted MV / LV transformers are widely used in Algeria’s distribution network. Unlike transformers in masonry substations, Pole-mounted transformers are highly exposed to surges caused by lightning, especially in regions with a high keraunic level. The protection devices of surge transformers are the spark gap and the surge arrester. In our case, the device used is the spark gap. In this paper, after the analysis of the incidents caused by lightning, we carried out a technical-economic analysis to study the profitability of the replacement of the spark gaps by surge arresters.

### A3-219 Pollution and Humidity Effects on Air Insulated Switchgear (AIS) of MV/LV Substations

F.REBBOUH, W. CHABANE - *Алжир*

Substation protection is one of the most important schemes in power system, a report has been developed by CREDEG on the causes and effects of pollution and humidity within indoor substation distribution substations environments and methods of mitigating these factors. This study briefly explains the effect of high relative humidity with pollution on damage. The study covers best practice for the design of substations and internal environment control, the factors affecting the environment within a substation and methods of mitigating these factors. This report demonstrates why it is extremely important to control the substation environment and this can be achieved by minimizing moisture ingress and pollution into substations and controlling the temperature and humidity within the building.

**A3-221 Digital Disconnector and smart sensors: example of integration in the condition base asset management cloud tool**

T.PEGOURET - *Франция*, E.STELLA - *Италия*

Nowadays the renewable energy is growing constantly, and this kind of green energy is subjected to daily and seasons variability whose prediction is difficult and need to be precise. Consequently, to maintain stability in the network, there is an increasing demand of switching operations in the HV substations.

This can produce in the HV substation a kind of stress hard to predict for each switching device and on power components in general.

The impact of these changes can affect also the HV disconnector. In the article is presented a possible smart solution that is focus on integration of the IoT technology to set up smart sensors and a cloud monitoring network integration.

Will be presented a real case application of a system of smart sensors integrated in the design of disconnectors that monitor the temperature generated in the live part and the correct alignment of fix and mobile contacts directly in the main current path. In this document is also presented a sensor that can forecast the right time to clean disconnector’s insulators.

The architecture of these sensors can be of different types and uses different technologies, the lowest common multiple is the application of electronic components to HV equipment.

Is presented the descriptions of these sensors and the main challenge solved to apply these sensors to HV live parts, a very harsh environment from climate point of view and from electromagnetic point of view.

When several sensors are applied to a single device in substations, new interactions must be taken into consideration. In particular, for each substation, several disconnectors are installed and each one, thanks to its sensors, produces a big quantity of data. The management of this new aspect is considered and in the article is presented how this is managed thanks to the possibility offered by the IoT.

A second new aspect to consider is the possible interferences between sensors of different devices, in the case of wireless communication. The solution proposed is based on the digital communication between sensors to the merging unit. The use of digital technology helps the common rejection mode to ambient noise.

At the end also another two important aspects are considered and presented in the article: the data representation and the data interpretation.

**A3-222 External flashover of a 245kV live tank circuit breaker**

D. CHUN, C. PONS, H. DIGARD - *Франция*

This article presents the case of an external flashover along the switch chamber insulator housing of a 245kV live tank circuit-breaker. The incident took place in a French thermal power plant connected to the 225 kV/50 Hz grid and operating since the 1970’s. This is the only known case recorded in France of an external flashover occurring on a circuit-breaker. In the following, we explain the conditions that led to this exceptional phenomenon and present the measures implemented following this incident.

The power plant is located in the immediate vicinity of the seashore and close to petrochemical factories. It is known to be exposed to severe saline and industrial pollution conditions. The

equipment is a 245kV outdoor live tank circuit breaker with a “d” class of pollution as defined by IEC 60815-1:2008 standard. It ensures about one hundred coupling and decoupling cycles per year. While the plant was in production, a process incident tripped the unit and caused the circuit- breaker to open. One of the circuit-breaker’s terminal was subjected to the grid voltage (225kV 50Hz). As the alternator was still excited and the turbine generator was rotating at 3000 rpm, the other terminal was also subjected to a voltage of 225kV. As these voltages were no longer synchronized, they were periodically in phase opposition. In these conditions, the voltage between the circuit-breaker terminals was higher and reached about 282kV RMS. This is a normal transient phase that occurs during each coupling and decoupling phase. The circuit-breaker is designed to withstand this voltage value.
Nonetheless, a flashover took place on one phase of the circuit-breaker at this exact moment. The voltages and currents recorded by the disturbance recorder on both sides of the circuit-breaker were analyzed. The electric arc current was about twice the nominal current of the plant and was flowing from the grid to the neutral point of the main transformer. At the time of the incident, the pollution level was estimated to be class “d”, and the humidity level was well above 70%. The high pollution level, coupled with the presence of two voltages in phase opposition at the circuit- breaker terminals explain the incident. The protective relays finally put an end to the incident by opening an upstream circuit-breaker.
Several sheds of the switch chamber insulator were broken and the lower and upper flanges were damaged by the electric arc. The damaged pole has been identically replaced.
Several solutions and mitigation measures were implemented in order to reduce the effect of the pollution on the equipment:
- As a short term solution, a silicone grease has been applied to the insulators.
- Modifications of the protection system have also been implemented in order to reduce the fault clearance time in case of a flashover.
- Laboratory tests on circuit-breakers with higher pollution class (class “e”) have been carried out.
- Following these tests, the existing circuit breakers have been replaced by one equipped with an interrupting chamber with a 30 % increased creepage distance.

### A3-223 Monitoring of asymmetric short circuit currents at a hydro power plant using electronic fibre optical current transformers

T.NEUMEIER - *Германия*, T.HEID, F.RENAUD, M.VO - *Швейцария*, M.YANIN - *Россия*

Optical current transformers (OCT) and other low-power instrument transformers (LPIT) have been available, and are running in several pilot projects, since more than a decade. The technological advantages of OCTs include a high precision for a wide dynamic range for both AC and DC currents as well as the highest level of safety on primary and secondary side, when compared to conventional CTs. This paper presents a solution implemented by Swiss TSO Swissgrid AG, to monitor asymmetric short-circuit currents using Flexible Electronic Fibre Optical Current Transformers (F-EFOCT) and digital fault recorders. Before installation and commissioning of the solution, the proof of concept for the performance of F-EFOCT combined with the digital fault recorder to precisely monitor asymmetric currents (AC with DC components) was established in laboratory tests and project-specific factory acceptance tests (FAT). For this purpose, different tests such as short circuit current injection, AC or DC as well as combined AC and DC current injections into the optical current sensor were performed. In this context, it could be verified that asymmetrical currents captured by the F-EFOCT were correctly recorded with real timestamps. In addition, the fault recorder combined the sampled values (SV) of current measurement from the F-EFOCT with voltages and currents originated from conventional measuring methods. The interoperability between the merging unit and the digital fault recorder, which are coming from different suppliers and are based on the IEC 61850-9-2 LE standard, has been proven and the stability of the communication between the different units on the process bus was given.

### A3-224 Accuracy study of a combined low-power instrument transformer in different climatic and pollution conditions

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The Power System & Transmission Engineering Centre (CIST) of the French electric utility company Électricité de France (EDF) has been studying the installation and use of low-power instrument transformers (LPIT) with numeric outputs in power plant substations and insular networks substations since many years. For this purpose and in order to gain more experience on long term performance of a digital instrument transformer, EDF R&D and CONDIS started a partnership to conduct a long-term investigation on a combined low-power instrument transformer (cLPIT) under extreme climatic and pollution exposure.
The cLPIT consists of a fiber optical current transformer (FOCT) mounted on a high voltage insulator column which integrates a capacitive voltage divider (CD) with a low voltage secondary output. The voltage transformer functionality is realized by an analog to digital converter (ADC) with optical output integrated in the base of the CD. Optical fibers are used for the transmission of the signals from the primary side to the merging units, which use the IEC 61850-9-2 communication protocol.
This paper presents an investigation of the behavior of a novel combined low-power instrument transformer with electronic voltage transformer (EVT) and optical current transformer (OCT) in various climatic conditions, along with the ageing influence caused by extreme weathering conditions on the primary parts and converters. The performance of the LPIT is evaluated at different times during the project based on comparison with a conventional solution.
Firstly, the accuracy of the combined electronic VT and optical CT was proven at different temperatures, according to the standard cycle. These measurements serve as a reference point for future comparison. Those accuracy tests were performed in December 2018 in EDF Lab Les Renardières facilities and have highlighted the importance of using reference setups with significantly better accuracy than the DUT itself.
In a second step, the cLPIT was installed at the end of year 2018 in the EDF Martigues test station, which is located at the coast of the Mediterranean Sea in the south of France. The LPIT will remain continuously energized for two years, in which the device will be exposed to severe environmental stress factors. The region is distinguished by a heavy pollution level (SPS class d in accordance with TS/IEC 60815-1). Periodic inspections are conducted to follow the evolution of the equipment. After one year of ageing, no degradation or malfunction of neither the cLPIT, nor the electronic processing unit (EPU) has been detected. The visual ageing inspection has shown some typical traces of material ageing for exposure to such an aggressive environment (industrial pollution and seaside effects). However, no signs of electrical activity or tracking on the insulator itself was seen and the surface hydrophobicity of the silicone sheds remains unaltered.
The third and final step in this project, is to verify the evolution of the accuracy properties of the cLPIT due to the pollution and ageing period. These tests will be performed beginning of 2021 at the same temperature levels as the reference points taken in the first step.

**A3-225 Development of Light Asset Models based on Data Mining**

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Electrical grid networks are strategic for the development of economies. They transmit the energy from the generation to where it is used to develop and ensure the human activities. During the last 30 years, world energy demand increased by 110% from 11000 TWh to 23000 TWh and in the next 20 years, it will continue to grow at the same path in expectance to reach out 34000TWh by 2040. To support this growing energy demand, deliver business objectives and optimize the performance across the entire network from power generation to the end consumer, the different actors in the field of energy need to master the condition of each of their asset. The improvement of efficiency, reliability and lifetime of substation is as key as the optimization of the related costs to manage High Voltage & Medium Voltage power equipment lifecycle. However, due to technological evolutions, vanishing electrical expertise, ageing assets and continuous pressure on operating and capital expenses, electrical grids are more exposed to complex and challenging environments, increasing exposure to failures.
In order to minimize the risk of default, assets are being even more monitored, generating huge amount of data. The collected information is then used to take maintenance and replacement decisions on assets. Sometimes, data is used to fulfill asset models in Asset Management software which supports the fleet management and optimize maintenance and replacement decision.

However, the increased number of measurements and checks is not always the right solution to improve reliability, availability and lifetime of an asset or a fleet of assets:
▪ Risk of right assignment comprehensions due to different level of data relevancy
▪ Quality of the recommendation depends on the quality of the model;
▪ Operational cost increases with the number of collected data
The solution is to monitor a selection of data of which influence is significant and acceptable in terms of cost of collection. Plenty of data's sources are available – Reliability survey by CIGRE, FMEA (Failure Mode and Effect Analysis) beside all data recorded either during inspection or by online monitoring solution. The main challenge is to deal with such an amount of heterogeneous data, select the right type and number of parameters and to determine the method and the frequency to collect them. In this way, an accurate model of the asset can be developed and fed, keeping in mind that the data collection cost shall stay relevant when compared to the cost of the asset itself and the cost related to the failure.
In this paper, it will be described the workflow to follow to develop new asset-type model and how to combine various sources of information and data mining to develop consistent and cost- effective analytics evaluating the real condition of the asset.

**Предпочтительная тема 3. Влияние распределенной генерации на базе ВИЭ и систем накопления энергии на оборудование магистральных и распределительных сетей**

### A3- First 170 kV / 50 kA GIS with Clean Air and Vacuum Interrupter Technology as a Climate-neutral Alternative to SF6

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This paper presents a development of a new SF6-free 170 kV / 50 kA GIS, in Korea so called E-GIS, for a rated current of 4,000 A qualified according to IEC and Korea Electric Power Corporation (KEPCO) standards. The GIS is based on totally climate-neutral clean air (dry and pure synthetic air with 80 % nitrogen and 20 % oxygen) insulation and vacuum switching technology for interrupting the switching capacity. Both technologies are well proven and fulfil all customers' views on performance, safety, total cost of ownership and improved sustainability by lowering the carbon footprint of the insulation gas to its minimum (global warming potential GWP = 0). Synthetic air has many advantages over other alternative gases. It is sustainable, highly reliable with excellent long-term stability and gas no greenhouse gas emissions during operation and all other handling processes. Operation, maintenance and recycling costs are lower in comparison to other F-Gas GIS solutions. Moreover, the toxicity caused by the decomposition gas after the arc is negligible and it is applicable below -30° without liquefaction.
The short circuit current interruption is handled with the well proven vacuum interrupter technology. The vacuum interrupter has been verified in medium voltages for decades and recently it has been increasing in utilization at high voltages. Synthetic air is more vulnerable than SF6 in terms of insulation performance, however the presented E-GIS is designed to be comparable to existing SF6 GIS by optimization of compactness and extendable to existing SF6 GIS with coexistence.
The paper present details of the design aspects as well as of the positive verification of performance tests. Additionally, the impact of GWP is presented and discussed based on life cycle assessment to underline and proof the environmentally sustainable effect. In fact, with this new GIS we can lower the GWP impact of 14 t CO2 equivalent per bay and year. Therefore, application of an insulation gas with a GWP = 0 could positively contribute to a CO2 reduction in Korea.

### A3-302 Benchmarking the suitability of a Bi-Stable Disc Spring as Novel Ultra-Fast Actuation Principle

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High Voltage Direct Current transmission lines have been well established for a long time. Especially the growing generation from renewable energy sources, which are usually located in remote areas, is nowadays a driving factor for transmission increase. The downside of point-to-point connections is their reliability and availability, which can be improved by connecting such lines to a grid. For this purpose circuit breakers are necessary. One solution is the Hybrid HVDC

circuit breaker, which relies on semiconductors as the current breaking elements. Unfortunately, their on-state losses are prohibitively high. To overcome this issue, an Ultra Fast Disconnector (UFD) in a parallel branch is used, which short-circuits the semiconductor stack during normal operation. The main requirements for such a device are an extremely short opening time and a low resistance path for the nominal current in closed position. Previous studies have demonstrated the importance of a short opening time: due to the low network impedance, HVDC fault current levels rise quickly and consequently require a larger interruption performance of the main breaker. Most of the known UFD designs rely on Thomson coils as actuators. While this principle works fine, it requires bulky and heavy contacts, which limits the speed of the actuator. A reduction of the opening time would lead directly to a lower short-circuit interruption capability requirement.
For this reason, alternative novel actuation principles with the potential of substantially decreasing the opening time of a UFD are investigated. In order to do this, the general design of a UFD is split into three parts: electric strength in open position, contact resistance and heat generation in closed position and actuation speed (mainly during opening). The requirements of each part can be conflicting with and even contradictory to each other. One example is the stroke: a shorter stroke results in shorter opening time, while a larger stroke offers a better electric strength.
The present work focuses on the actuator and presents the use of a bi-stable disc spring as main actuation component. Such a spring is relatively light and offers a short opening time. The design as well as the experimental static and dynamic characterization are presented in this work.
The potential applicability of such an actuation mechanism goes beyond the application in UFDs and could enable also other switchgear applications where fast actuation is beneficial, e.g. controlled switching.

**A3-303 Performance tests of circuit-breakers for controlled switching**

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Controlled switching of circuit-breakers is a cost-efficient way to increase the stability of the power system, improve the power quality and reduce the stresses of high voltage equipment. It becomes increasingly important as the growing use of renewables requires a more frequent network reconfiguration. Capacitor banks, phase shift transformers or shunt reactors have to be switched at certain network conditions for stable power system operation.
Inrush currents and accompanying voltage dips should be limited to a certain value to avoid unnecessary disturbances. Each network situation requires a different strategy for the best closing or best opening instant of the circuit-breaker. A precise timing for the switching is crucial, and the required precision is in the range of milliseconds. This is a true challenge for high voltage circuit-breakers, which are large and heavy mechanical systems.
The presented paper will address the required testing of circuit-breakers according the new IEC draft standard 62271-113. The focus is on closing of the circuit-breaker:
Rate of Decrease of Dielectric Strength (RDDS), mechanical behavior, the statistics of breakdown during making, and the statistical characteristics of the mechanical operations are measured and analyzed. The tested circuit-breakers (single-break 420 kV GIS) were tested with two different closing speeds: velocity 1 and velocity 2 (higher than velocity 1 by 50%). The tests were performed at different drive, ambient, idle time and control conditions.
Furthermore, the assessment of circuit breaker for various load application is carried out according to CIGRE TB-757. The assessment results show that the tested breaker is well suited to energize at any point on the power frequency voltage curve as its RDDS is larger than 1 pu. The higher closing speed needs to be chosen. Stable timing correlation of the auxiliary contacts in respect to the arcing contacts was checked to make sure that it is possible to rely on these signals in service applications.
The measured mechanical scatter follows a normal distribution, and the tested breaker has a distribution with a width for three standard deviations (3σ) of 0.5 milliseconds. This means that more than 99% of the closing events will happen within ±0.5 ms of the intended target. Influences of the ambient temperature, control voltage, drive condition or idle time can be compensated with a suitable controller. However, for best targeting after long idle times – where the statistical information is obviously limited – exercising of the breaker before switching gives the best results.

Field measurements for controlled energization of capacitive & inductive loads with the test breaker at commissioning are evaluated and presented. An important finding is that it is counterproductive to be “conservative” and underestimate the RDDS of the breaker. This may create serious difficulties during commissioning and achieving optimum mitigation performance because the targeted points close to zero are not reached and the registered making instants are misinterpreted as a very large mechanical scatter of the used breaker.