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Highlights

Phenomena and Interruptions

Future Grid in a Dynamic Spiral

Discovering Thoughts, Inventing Future

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Correlations between Meteorological Phenomena and Interruptions in the Supply of Electric Energy in a Power Supplier

By Marcos Antonio Lopes Freixo Filho & Ana Julia Righetto

Abstract- There are several technologies in the area of engineering, new and old, currently used with the objective of reducing the impacts of meteorological phenomena on electrical energy distribution networks. However, they still constitute one of the biggest challenges for companies around the world, the mitigation of the number of interruptions in the energy supply, in the face of the weather. This research work seeks something similar, which is to offer another analysis, from the point of view of data science, studying the correlation between the meteorological phenomena recorded by the Climatempo Monitoring and Alert System and the interruptions in the energy supply in two main cities of Maranhão State, with unknown causes, recorded by the control system used by the integrated operations center of the local power supplier, in an attempt to find some kind of fragility in the electrical system, not yet identified, that allows its improvement.

Palavras-chave: *DEC, FEC, clima, transformadores de distribuição.*

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CORRELATIONSBETWEENMETEOROLOGICALPHENOMENAANDINTERRUPTIONSINTHESUPPLYOFELECTRICENERGYINAPOWERSUPPLIER

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Correlations between Meteorological Phenomena and Interruptions in the Supply of Electric Energy in a Power Supplier

Correlações entre Fenômenos Meteorológicos e Interrupções no Fornecimento de Energia Elétrica em uma Distribuidora

Marcos Antonio Lopes Freixo Filho α & Ana Julia Righetto σ

Resumo- Há diversas tecnologias no campo da engenharia, novas e antigas, utilizadas atualmente com o intuito de reduzir os impactos dos fenômenos meteorológicos nas redes de distribuição de energia elétrica. Porém, ainda assim constituem um dos maiores desafios para as companhias ao redor do mundo, a mitigação do número de interrupções no fornecimento de energia, frente às intemperes. Este trabalho de pesquisa busca algo semelhante, que é oferecer outra análise do ponto de vista da ciência de dados, estudando a correlação entre os fenômenos meteorológicos registrados pelo Sistema de Monitoramento e Alertas do Climatempo, e as interrupções no fornecimento de energia em duas principais cidades do Maranhão com causas desconhecidas, registradas pelo sistema de controle utilizado pelo centro de operações integrados da distribuidora de energia local,na tentativa deencontrar algum tipo de fragilidade no sistema elétrico, ainda não identificada, que permita o seu aprimoramento.

Palavras-chave: DEC, FEC, clima, transformadores de distribuição.

Abstract- There are several technologies in the area of engineering, new and old, currently used with the objective of reducing the impacts of meteorological phenomena on electrical energy distribution networks. However, they still constitute one of the biggest challenges for companies around the world, the mitigation of the number of interruptions in the energy supply, in the face of the weather. This research work seeks something similar, which is to offer another analysis, from the point of view of data science, studying the correlation between the meteorological phenomena recorded by the Climatempo Monitoring and Alert System and the interruptions in the energy supply in two main cities of Maranhão State, with unknown causes, recorded by the control system used by the integrated operations center of the local power supplier, in an attempt to find some kind of fragility in the electrical system, not yet identified, that allows its improvement.

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I. Introdução

O setor elétrico brasileiro, para que a energia possa chegar até os seus consumidores, passa por quatro etapas: a geração, a transmissão, a distribuição e a comercialização. A distribuição é responsável pelo varejo, vendendo a energia comprada em leilões e as recebendo pela transmissão. Este é um mercado regulado, com a participação de empresas públicas e privadas, de capital aberto, ou fechado. Segundo o Portal da Indústria (2021), existem no Brasil 131 concessionárias, permissionárias e cooperativas de distribuição de energia elétrica.

A Agência Nacional de Energia Elétrica [ANEEL], é o órgão regulador do mercado de energia elétrica. Dentre muitas de suas atribuições, cabe a ela regular a qualidade no fornecimento e expansão do sistema elétrico nacional. Para medir a qualidade, ela utiliza dois indicadores regulatórios que são metas estabelecidas à todas as distribuidoras do país.

O [DEC], sigla para Duração Equivalente de Interrupção por Unidade Consumidora, mede a duração equivalente de interrupção por unidade consumidora, ou o tempo que, em média, no período de observação, cada unidade consumidora ficou sem energia elétrica. Já o [FEC], sigla para Frequência Equivalente de Interrupção por Unidade Consumidora, se refere a frequência equivalente de interrupção por unidade consumidora, o número de interrupções ocorridas, em média, no período de observação. É de grande importância para as distribuidoras atender a estas regras regulatórias por apresentar um risco financeiro, receber ocasionalmente uma multa pela má gestão destes indicadores, como o caso de uma distribuidora de Minas Gerais, que recebeu um auto de infração em mais de doze milhões de reais, como informou o Canal Energia (2018).

Dentre os fatores que podem levar a uma interrupção no fornecimento de energia, temos o baixo investimento e manutenção do sistema elétrico, acidentes quaisquer com a rede de distribuição, ou mesmo na transmissão, o que normalmente é

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expurgado dos resultados das distribuidoras de energia nos cálculos da agência reguladora, e os fenômenos climáticos, ou meteorológicos que por ventura derrubem o sistema, como descargas elétricas, ventanias, entre outros fatores.

Segundo Silva (2013), em nosso país, aproximadamente 70% dos desligamentos na transmissão e 40% na distribuição, são provocados por raios, sendo o número de transformadores queimados por descargas elétricas atmosféricas em torno de 40%. Tais números causam um impacto considerável no fornecimento de energia, o que pode ser constatado pela alta correlação entre a incidência de descargas elétricas e os índices de qualidade da maioria das empresas do setor elétrico.

No trabalho de Wronscki et al (2003), após a utilização de modelos estatísticos, foram encontradas evidências de maior número de atendimentos e maior tempo médio de atendimento nas chamadas emergenciais de interrupção no fornecimento para a condições meteorológicas de vento e chuva, enquanto houve um menor número para a condição temperatura.

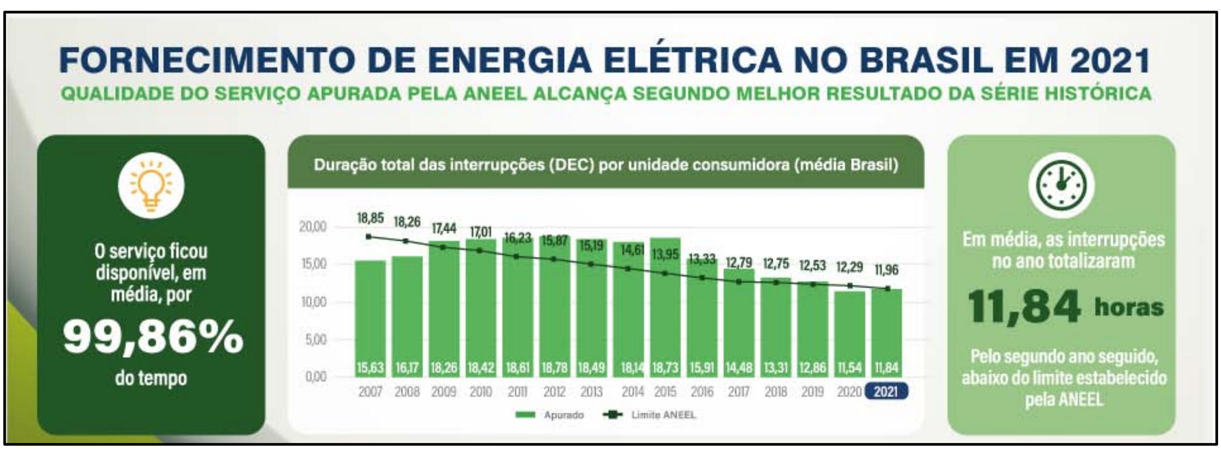
A distribuidora de energia do Maranhão, que durante anos permaneceu entre as três melhores empresas do país no quesito qualidade no fornecimento de energia, despencou em 2021 para os últimos lugares, de acordo com o último ranking divulgado pela [ANEEL] (2022). A empresa acredita que isto não se deve aos investimentos realizados na rede, que na verdade, ano após ano são cada vez maiores, mas se deve a um ano atípico de muitos registros de fortes precipitações, enchentes, ventanias, descargas elétricas atmosféricas, entre outros fenômenos climáticos.

Este trabalho tem como objetivo verificar e quantificar a correlação entre os fenômenos meteorológicos e a quantidade de ocorrências de interrupção no fornecimento de energia elétrica registradas pelo centro de operações integradas da distribuidora energética do Estado do Maranhão, para os municípios de São Luís e Imperatriz.

II. Material e Métodos

O princípio que irá nortear este trabalho de pesquisa, a formar a base de dados final para estudos, ou seja, após a fase de "data wrangling", é que esta base de dados reflita muito bem o fenômeno a ser estudado, que é a interrupção no fornecimento de energia, que seja capaz de explicar o preceito principal de que, apesar das dificuldades enfrentadas particularmente no país, em suma, o fornecimento de energia elétrica passa mais tempo em continuidade do fornecimento, do que interrompido, ou suspenso.

Para se ter uma dimensão sobre tal fato, o indicador do [DEC] em 2021, valor apurado na média para todo o Brasil, segundo o Governo Federal (2022), ficou em 11,84 horas. Em outras palavras, de um total de 8.760 horas do ano de 2021, em 99,86% do tempo a energia esteve em pleno fornecimento, sem interrupção, no Brasil inteiro, como pode ser constatado na Figura 1.



Fonte: Governo Federal (2022)

Figura 1: Recorte do Resultado do [DEC] em 2021

Ainda que o resultado para o Maranhão tenha ficado acima deste valor, registrando 29 horas, estando 99,67% do tempo em pleno fornecimento, conforme informado pelo distribuidora de energia em seu site de relacionamento com os investidores, em março de 2022, este número continua apontando para um fato supra relevante: a base de dados deve dar alicerce para realizar o estudo de um fenômeno raro, ou seja, que além dos dados sobre as interrupções no fornecimento de energia, a base deve possuir cada hora em que o fenômeno não aconteceu, o período em que o fornecimento de energia não foi interrompido.

Seguindo estra premissa, este trabalho de pesquisa experimental, vem trabalhar a hipótese da existência de uma correlação entre os fenômenos meteorológicos, e a quantidade de vezes em que o sistema elétrico teve sua distribuição interrompida, porém somente dos dados sinalizados como causa desconhecida, atendida por transformadores de distribuição, em dois municípios do Estado do Maranhão.

O centro de operações integradas[COI], setor responsável por manter o sistema de distribuição de energia elétrica em pleno atendimento para a população maranhense, possui em seus controles, uma base de registros de interrupções do fornecimento de energia, e seus equipamentos afetados, chamados de componentes, com informações que caracterizam em detalhe a sua tipificação, informações a princípio muito relevantes para esta pesquisa para verificarmos se há um padrão de componentes mais suscetíveis, ou não, às intemperes climáticas.

Com autorização da empresa, foram colhidos dados dos últimos doze meses, compreendidos entre agosto de 2021 e julho de 2022, somente dos equipamentos de transformadores de distribuição, já que toda interrupção de energia, que afete o bem-estar dos consumidores, acaba passando por este tipo de equipamento, segundo o especialista do próprio setor.

Outro fato importante é que, com a ajuda deste especialista, foram excluídas desta amostra de dados, todas as interrupções de energia derivadas da intervenção humana, como acidentes de trânsito, desligamentos programados, sobrecargas do equipamento causadas pelo consumo, não realização de poda de árvores abaixo da rede elétrica, para citar alguns, o que deixa a base de informações mais limpa para a realização deste estudo, já que todas as interrupções citadas têm a sua causa conhecida, e registrada no sistema.

Coletada a primeira parte dos dados, a segunda parte foi fornecida junto com a área conhecida como geoprocessamento, e lá foram coletadas as informações a respeito do clima, para as mesmas cidades. A companhia de energia possui um contrato de prestação de serviços com a empresa Climatempo, e através do Sistema de Monitoramento e Alertas do Climatempo, com a autorização da distribuidora, foram coletadas também informações do mesmo período da base coletada anteriormente, referentes a pluviometria, descargas elétricas atmosféricas, rajadas de vento, velocidade média do vento ao longo do dia, temperatura média, máxima e mínima.

As variáveis possuem precisões diferentes para relatar o período em que aconteceram, variando entre a precisão da hora, minuto e segundo em que ocorreram, como os dados de interrupções de energia, e os dados das descargas elétricas atmosféricas, e até informação que trata de resultado válido pelo dia inteiro, como velocidade do vento, e as informações sobre temperatura. Todas foram colocadas na mesma escala de tempo, demonstrando os fatos ocorridos a cada uma hora do dia, durante 365 dias. Assim, foram criadas quatro variáveis para identificar o tempo: ano, mês, dia e hora.

Um fato importante é que tal base neste momento contém apenas informações relativas às interrupções, e como estava o clima naquele exato momento, entretanto, como já mencionado, ainda que uma distribuidora no território nacional tenha os piores indicadores de continuidade no fornecimento de energia, mesmo assim o sistema elétrico desta distribuidora hipotética estaria em pleno funcionamentona esmagadora parte do tempo. Desta forma, foram reproduzidos os dados que representam o período em que a energia estava emplenadistribuição, para cada tipo diferente de transformador de distribuição, trazido na amostra de interrupções, com o mesmo período de tempo da amostra, em dias e horas, e devidamente cruzada com a base climatológica, para se conhecer as exatas condições do tempo neste mesmo exato período. Para diferenciar as duas informações na base de dados, foi criada uma variável chamada de “interrupções”, do tipo numérica, atribuindo a quantidade “1” para as observações relativas a uma interrupção no fornecimento de energia, e “0” para as observações que representam o período em que a energia estava em pleno funcionamento.

Cabe salientar que foram excluídas desta base de dados de observações em que a energia estava em plena distribuição, as observações que coincidem temporalmente com a base de interrupções, afinal, exatamente neste exato período, a energia fortuitamente estava suspensa em seu fornecimento. Também, no intuito de explorar uma outra possibilidade que pode ser relevante para a pesquisa, foi criada uma variável chamada “raio”, do tipo binária, para indicar a presença de raios naquela exata hora relada atribuindo o valor 1, e 0 quando o fato não havia ocorrido, o que é diferente da variável “descargas_atm”, que apresenta a quantidade de descargas elétricas atmosféricas dentro daquela mesma observação.

Finalmente com as duas bases de dados unidas (com e sem interrupções), encerrando a etapa de“data wrangling” da coleta de dados, para que se garanta a aleatoriedade da informação, quanto ao objeto desta pesquisa experimental, e permitindo analisar se este estudo se trata de um caso em que o melhor modelo estatístico deva levar em conta o estudo de um fenômeno raro, considerando o fato de que energia elétrica passa mais tempo em plena distribuição, do que suspensa.

Por fim, em razão do tamanho da base de dados para este estudo, se fossem considerados todos os municípios do Estado do Maranhão, ainda que utilizando dados relativos ao período de apenas um ano, foram escolhidos apenas dois dos principais municípios do Estado: São Luís, e Imperatriz. O estudo poderia se limitar a capital do Estado (São Luís), por seu tamanho e importância. Todavia, a cidade de

Imperatriz possui características completamente diferentes, no que se diz respeito ao clima, relevo, economia, ou outras não citadas, o que torna ainda mais interessante checar neste estudo, se há semelhanças nos resultados obtidos entre os dois municípios, o que poderia levantar outras hipóteses, para outros trabalhos futuros.

III. Modelo de Regressão de Poisson

A metodologia estatística que foiadotada neste estudo foia aplicação do modelo de regressão de Poisson. Os modelos de regressão Poisson e o modelo de regressão binomial negativo fazem parte do que éconhecido por modelos de regressão para dados de contagem, que têm porobjetivo analisar o comportamento, em função de variáveis preditoras, de umadeterminada variável dependente que se apresenta na forma quantitativa, comvalores discretos e não negativos, exatamente como o objeto de estudo deste trabalho, onde a princípio não é possível fracionar o evento "interrupção do sistema elétrico" (não considera-se neste estudo os casos em que a energia esteve em oscilação quanto ao fornecimento), tendo sempre sua quantificação como números discretos e positivos.

Considerando o que afirma Fávero e Belfiore (2022, p.149), ao mencionar que no caso de ocorrência de fenômenos raros, com baixa probabilidade de sucesso ($p \rightarrow 0$), sob determinada exposição (unidade temporal, espacial, social, etc.)., como no caso desta pesquisa experimental, em determinado intervalo de tempo, o modelo de distribuição Poisson se torna o prioritário a ser explorado.

Expressão do modelo de Poisson:

$$\ln(\hat{Y}_i) = \ln(\lambda_{poisson\ i}) = \alpha + \beta_1.X_{1i} + \beta_2.X_{2i} + \ldots + \beta_k.X_{ki} \qquad \text{form. (1)}$$

Em que $\ln(\hat{Y}_i)$ ou $\ln(\lambda_{poisson\ i})$ é definido a partir de uma função de ligação canônica que é proposta com base na definição dos logaritmos das funções de verossimilhança oriunda da função densidade/ probabilidade da distribuição Poisson, αrepresenta os termos do intercepto, $\beta_k$são os coeficientes de cada variável explicativa e correspondem aos parâmetros a serem estimados, eX_{ki}são as variáveis explicativas.

Fórmula da probabilidade da distribuição Poisson:

$$p(Y_i = m) = \frac{e^{-\lambda_i}.\lambda_i^m}{m!} \qquad \text{form. (2)}$$

Em que $p(Y_i = m)$ é afunção da probabilidade de um evento, no modelo de regressão de Poisson, determinada por uma observação i (i = 1, 2, ..., n), "n" é o tamanho da amostra, e possui a probabilidade de ocorrência de uma contagem "m", em uma determinada exposição (período, área, região, entre outros exemplos), em que "**λ**" é o número esperado de ocorrências ou a taxa média estimada de incidência do fenômeno em estudo para uma dada exposição

A título de comparação de melhor modelo, também foi aplicado neste estudo o modelo de regressão binomial negativo, também conhecido como Poisson Gama, outro modelo de contagem aqui citado. A diferença básica entre os dois modelos,é que o modelo binomial negativo é mais utilizado para os casos de superdispersão, ou inflação de zeros da amostra, onde a variância da variável dependente é maior que sua própria média. Segundo Fávero e Belfiore (2022, p.696), a superdispersão é comumente gerada pela presença de maior heterogeneidade nos dados entre observações da amostra.

Expressão do modelo Binomial Negativo:

$$\ln(\hat{Y}_i) = \ln(\lambda_{bneg\ i}) = \alpha + \beta_1.X_{1i} + \beta_2.X_{2i} + \ldots + \beta_k.X_{ki} \qquad \text{form. (3)}$$

Em que $\ln(\hat{Y}_i)$ ou $\ln(\lambda_{bneg\ i})$ é definido a partir de uma função de ligação canônica que é proposta com base na definição dos logaritmos das funções de verossimilhança oriunda da função densidade/ probabilidade da distribuição Poisson Gama, ou Binomial Negativa, αrepresenta os termos do intercepto, $\beta_k$são os coeficientes de cada variável explicativa e correspondem aos parâmetros a serem estimados, e X_{ki}são as variáveis explicativas.

Fórmula da probabilidade da distribuição Binomial Negativa:

$$p(Y_i = m) = \frac{\delta^\theta.m_i^{\theta-1}.e^{-m_i.\delta}}{(\theta-1)!} \qquad \text{form. (4)}$$

Em que $p(Y_i = m)$ é a função de probabilidade no modelo binomial negativo determinada por uma observação i (i = 1, 2, ..., n), "n" é o tamanho da amostra, onde θ é chamado de parâmetro de forma e deve ser maior que zero, e **δ** é chamado de parâmetro de taxa de decaimento, também maior que zero.

A hipótese nula para este estudo será a baixa ou nenhuma correlação entre os fenômenos meteorológicos e as interrupções no fornecimento de energia elétrica em uma distribuidora, abrindo a possibilidade de estudar outros fatores, como a fadiga dos equipamentos, vida útil da rede de distribuição, ou mais fatores, que possam ter preponderância maior na suspensão ocasional da distribuição energética de eletricidade.

Ainda, foram feitas análises de correspondências múltiplas, que se trata de uma técnica multivariada que possibilita a investigação de associação com mais de duas variáveis categóricas, conformeFávero e Belfiore (2022, p.463), no intuito de perceber a relação de interdependência entre as variáveis utilizadas neste estudo, trabalhando somente com as observaçõesonde ocorreram as interrupções do fornecimento de energia elétrica, nas duas amostras os dados.

As técnicas de análise de correspondência são métodos de representação de linhas e colunas de tabelas cruzadas de dados, como coordenadas em um gráfico, chamado de mapa perceptual, a partirdo qual se podem interpretar as similaridades e diferenças de comportamento entre variáveis, e entre categorias.

Essa técnica tem como principal objetivo avaliar a significância dessas similaridades, reduzindo suas dimensões, de modo a determinar coordenadasdas categorias com base na distribuição dos dados em tabelas cruzadaspara,a partir dessas coordenadas, construirmapas perceptuais, que nada mais são que diagramas de dispersão que representam as categorias das variáveisna forma de pontos em relação a eixos de coordenadas ortogonais, fazendo delas,na realidade, mapas de categorias.

O método para realizar a análise consiste em transformar as variáveis qualitativas em variáveis binárias, obtendo daí uma matriz binária. Com base nesta matriz binária, é obtido a inércia principal total na [ACM]. Supondo que a matriz binária seja semelhante a uma tabela de contingência da análise de correspondência, é possível obter a inércia principal parcial das dimensões, seus autovalores, autovetores, e posterior coordenadas desta matriz.

Outro método alternativo é a combinação em uma única matriz, as tabelas de contingências com os cruzamentos de todos os pares de variáveis. Essa matriz resultante, quadrada e simétrica, é conhecida por matriz de Burt, como explica Baltar (2005).

Só participaram da [ACM] as variáveis que apresentaram associação estaticamente significativa, com pelo menos uma variável contida na análise, por meio do teste do X^2. Caso alguma delas não apresentasse associação com outras, estas ficaram excluídas da análise de correspondência. Ao elaborar o mapa perceptual, são representadas no mapa as coordenadas dasdimensões que apresentam a inércia principal parcial maior do que a média dainércia principal total por dimensão.

A aplicação dos modelos estatísticos se deu através da linguagem R, utilizando o software RStudio versão 1.4.1106. A base final foi exportada para o formato de planilha, e tratada em banco de dados SQL Server.

IV. Resultados e Discussão

a) São Luís

Foram carregados os dados da amostra de São Luís, coletada na distribuidora de energia no R com um total de 272.151 observações e 12 variáveis. Os dados podem ser vistos através da função “glimpse()”, conforme apêndice.

Para reforçar essa possibilidade conceitual, de que o objeto de estudo deste trabalho de pesquisa, se trata de um fenômeno raro, foi realizado o diagnóstico preliminar para observação de eventual igualdade entre a média e a variância da variável dependente INTERRUPCAO, cujos resultados foram respectivamente 0,0180268 e 0,0177019, valores muito próximos, o que indica fortemente que de fato, o modelo estatístico mais indicado para explicar a contagem de interrupções de energia elétrica da amostra de dados de São Luís, seja um modelo de regressão Poisson.

Utilizando a função “glm()”, fez-se a estimação deste modelo, colocando a variável INTERRUPCAO como a variável dependente, e as outras onze variáveis, já citadas, como variáveis explicativas.

O primeiro resultado apurado com base no modelo de regressão de Poisson, confirma a hipótese desta pesquisa experimental, de que existe de fato uma correlação entre os fenômenos meteorológicos e as vezes em que o fornecimento de energia elétrica foi interrompido aos consumidores de São Luís, pois pelo menos um beta de uma variável com informações da meteorologia no momento em que acontece a interrupção, teve o seu p-valormenor que 0.05, ou seja, podemos admitir o modelo estatísticos perfeitamente correlacionado, para fins preditivos, como vê-se na Tabela 1, através da função “summary()”.

Tabela 1: Summary do Modelo Poisson da base Coletada de São Luís

Variáveis	Estimativa	Erro padrão	Valor de Z	Pr(>|z|)
(Intercepto)	0,7762	0,6353	1,2220	0,2218
FASESABC	-0,3258	0,4756	-0,6850	0,4934
FASESAC	-2,0067	0,5547	-3,6170	0,0003
FASESB	-4,9644	0,5544	-8,9540	<2e-16
KVA10	-5,8039	0,4141	-14,0140	<2e-16
KVA1000	-5,3779	0,4167	-12,9070	<2e-16
KVA112,5	0,0339	0,0417	0,8140	0,4158

KVA15	-3,0510	0,1446	-21,0960	<2e-16
KVA150	-0,4834	0,0484	-9,9800	<2e-16
KVA1500	-7,1696	1,0024	-7,1520	0,0000
KVA1750	-6,0710	0,5833	-10,4080	<2e-16
KVA2000	-6,4765	0,7120	-9,0960	<2e-16
KVA225	-2,9794	0,1396	-21,3490	<2e-16
KVA25	-7,1520	1,0015	-7,1410	0,0000
KVA250	-7,1690	1,0024	-7,1520	0,0000
KVA2600	-7,1696	1,0024	-7,1520	0,0000
KVA30	-2,9908	0,1431	-20,9010	<2e-16
KVA300	-3,9313	0,2119	-18,5510	<2e-16
KVA3000	-7,1696	1,0024	-7,1520	0,0000
KVA350	-6,4765	0,7120	-9,0960	<2e-16
KVA3500	-7,1690	1,0024	-7,1520	0,0000
KVA45	-1,2695	0,0760	-16,7130	<2e-16
KVA5	-5,9503	0,4556	-13,0590	<2e-16
KVA500	-4,6847	0,3004	-15,5930	<2e-16
KVA612,5	-6,4765	0,7120	-9,0960	<2e-16
KVA725	-6,4765	0,7120	-9,0960	<2e-16
KVA75	-0,1176	0,0463	-2,5430	0,0110
MEDIA_CLIENTES	-0,0006	0,0004	-1,3650	0,1722
PLUVIOMETRIA	0,0154	0,0025	6,0680	0,0000
TEMP_MIN	-0,0720	0,0149	-4,8420	0,0000
TEMP_MAX	-0,0200	0,0132	-1,5130	0,1303
TEMP_MEDIA	NA	NA	NA	NA
DESCARGAS_ATM	0,0015	0,0007	2,0870	0,0369
RAIO	0,3236	0,0633	5,1090	0,0000
RAJADA	0,0042	0,0010	4,0830	0,0000
VENTOS_KMH	0,0021	0,0015	1,4400	0,1499

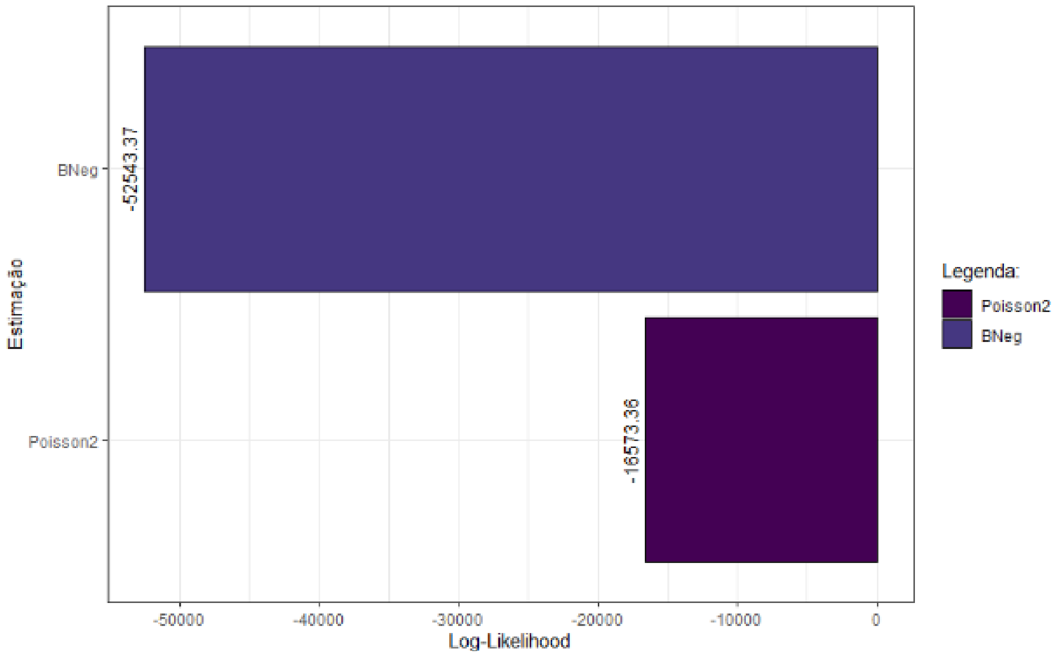
Fonte: Resultados originais da pesquisa

No intuito de evitar efeitos prováveis de multicolinearidade entre as variáveis meteorológicas que naturalmente tendem a ter resultados próximos, foi feito uma nova estimação do modelo, onde foram consideradas apenas as variáveis que foram estatisticamente significantes para o objeto deste estudo. Desta forma, foram retiradas as variáveis TEMP_MAX, TEMP_MEDIA, DESCARGAS_ATM, VENTOS_KMH, e atribuindo o nome de modelo_poisson2.

Para fins de comparação, e se aproximar da certeza de que o modelo estatístico não se trata de uma distribuição Binomial Negativa, corroborando com o diagnóstico preliminar que compara a média e a variância da base coletada de dados de São Luís, fez-se necessário carregar o modelo binomial negativo desta mesma base, utilizando a função “glm.nb()”.

Segundo Bussab e Morettin (2005), o princípio da verossimilhança explica que se deve escolher aquele valor do parâmetro desconhecido que maximiza a probabilidade de obter a amostra particular observada, ou seja, o valor que torna aquela amostra a “mais provável". Esse princípio foi enunciado por Ronald Aylmer Fisher pela primeira vez em 1912 e, em 1922, deu-lhe forma mais completa, introduzindo a expressão Log-Likelihood(verossimilhança).

Em outras palavras, o método de máxima verossimilhança consiste em estimar o parâmetro λ por uma amostra aleatória X1, ..., Xn independente e igualmente distribuída de X. Na Figura 2 é feita a comparação entre os dois modelos estatísticos, comparando o Log-Likelihoodde ambos os modelos estatísticos aplicados na amostra de São Luís.



Fonte: Resultados originais da pesquisa

Figura 2: Comparação de Log Lik Entre os Modelos Poisson (2) e Binomial Negativo (Poisson Gama)

De acordo com Fávero e Belfiore (2022), quanto menor for o Log-Likelihood na comparação entre modelos estatísticos, melhor é o ajuste do modelo à distribuição da amostra. Assim, para este estudo, será considerado o modelo Poisson (modelo_poisson2) para explicar a contagem dos dados de interrupção de fornecimento de energia elétrica em São Luís do Maranhão.

Apenas para exemplificar a importância desta pesquisa experimental, tomando o modelo estatístico fundamentadamente adotado, através da função "predict", é possível estimar em aproximadamente 36,6%, a probabilidade de ocorrer uma interrupção do fornecimento de energia elétrica de um transformador de distribuição com três fases conectadas (ABC), de carga de 112,5Kva, sob uma chuva de 15 milímetros, com uma temperatura mínima de 22ºC, na presença de raios, rajadas de vento de 30Km/h,conforme pode ser visto no apêndice deste trabalho.

Ainda, cabe neste trabalho explorar a relação que cada uma destas variáveis que explicam as interrupções no fornecimento de energia, na amostra utilizada no modelo de Poisson, se relaciona-se entre si. Para isto, foi gerada um segundo "dataframe", a partir da base denominada de final.

Em um novo "wrangling" dos dados, para que se possa realizar uma análise de correspondência, foram criadas novas variáveis para minimizar a quantidade de rótulos a serem exibidos num mapa perceptual que será feito com a análise de correspondência múltipla [ACM].

A variável PLUVIOMETRIA, foi substituída pela variável PLUV_TIPO, agora como uma variável categórica, contendo uma classificação da chuva baseada na sua intensidade medida na quantidade de milímetros registrados naquela hora. A classificação da intensidade da chuva obedeceu aos critérios adotados pela Organização Meteorológica Mundial – OMM (2018), e para nossa amostra, se dividiu entre fraca, moderada e forte.

A variável RAJADA foi substituída pela variávelRAJADA_TIPO, e suas categorias foram classificadas segundo a escala Beaufort, também disciplinada pela OMM, escala baseada na velocidade do vento registrada conforme Tabela 2.A variável VENTO foi excluída por possíveis relações de multicolinearidade na amostra com outras variáveis, como já mostradoneste trabalho.

A variável RAIO foi mantida, mas para fins de exibição dos rótulos de dados no mapa perceptual da [ACM], os valores "0" e "1", foram substituídas respectivamente pelas categorias "RAIO_NAO" e "RAIO_SIM". A variável DESCARGAS_ATM foi excluída, sem substituta, por não ter sido encontrado quaisquer classificações advindas de instituições oficiais ou norma científica, nas pesquisas deste trabalho, que definissem a intensidade de descargas elétricas atmosféricas.

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Tabela 2: Escala Beaufort, Limitada Até A Maior Velocidade Registrada Nas Amostras

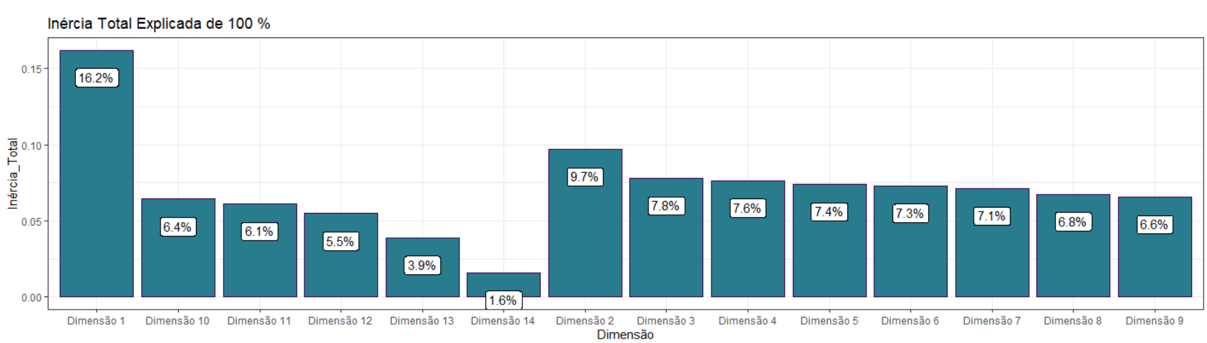
Grau	Designação	m/s	km/h	Efeitos em terra
0	Calmo	<0,3	<1	Fumaça sobe na vertical
1	Aragem	0,3 a 1,5	1 a 5	Fumaça indica direção do vento
2	Brisa leve	1,6 a 3,3	6 a 11	As folhas das árvores movem; os moinhos começam a trabalhar
3	Brisa fraca	3,4 a 5,4	12 a 19	As folhas agitam-se e as bandeiras desfraldam ao vento
4	Brisa moderada	5,5 a 7,9	20 a 28	Poeira e pequenos papéis levantados; movem-se os galhos das árvores
5	Brisa forte	8 a 10,7	29 a 38	Movimentação de grandes galhos e árvores pequenas
6	Vento fresco	10,8 a 13,8	39 a 49	Movem-se os ramos das árvores; dificuldade em manter um guarda-chuva aberto; assobio em fios de postes
7	Vento forte	13,9 a 17,1	50 a 61	Movem-se as árvores grandes; dificuldade em andar contra o vento
8	Ventania	17,2 a 20,7	62 a 74	Quebram-se galhos de árvores; dificuldade em andar contra o vento; barcos permanecem nos portos
9	Ventania forte	20,8 a 24,4	75 a 88	Danos em árvores e pequenas construções; impossível andar contra o vento
10	Tempestade	24,5 a 28,4	89 a 102	Árvores arrancadas; danos estruturais em construções
11	Tempestade violenta	28,5 a 32,6	103 a 117	Estragos generalizados em construções

Fonte: Resultados originais da pesquisa

De forma semelhante, as três variáveis de temperatura foram substituídas por três novas variáveis categóricas, TEMP_MIN_FAIXA, TEMP_MAX_FAIXA e TEMP_MED_FAIXA, onde de forma arbitrária, por também não ter encontrado literatura semelhante às outras variáveis anteriormente citadas, que agrupam as temperaturas por faixa.

Por último, para fins demonstrativos, destinados a orientar estudos posteriores a este trabalho, foram selecionados apenas três transformadores de distribuição na amostra, em razão de serem os mais utilizados pela Companhia, da igual forma, a fase escolhida a foi a "ABC".

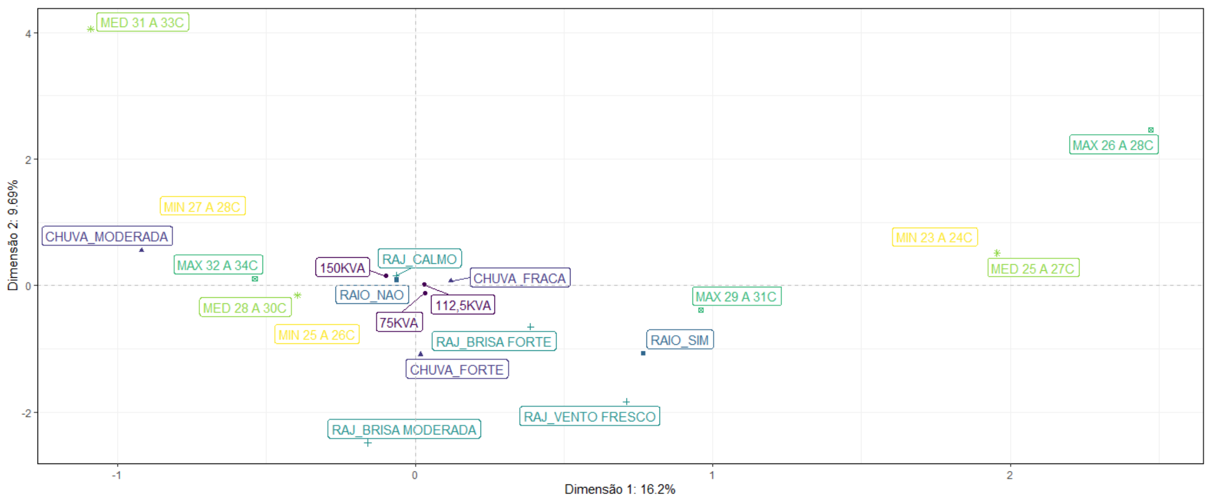
Através do comando "mca()", obtemos a análise de correspondência múltipla da amostra. Foram obtidas 15 dimensões, e a inércia total explicada se deu conforme exposto no Figura 3.



Fonte: Resultados originais da pesquisa

Figura 3: Inércia Total Explicada da [ACM] da Amostra

Por fim, para fins de exemplo de estudos que possam ser explorados pelas áreas de engenharia, com outros equipamentos, em outras regiões do Estado, ou mesmo em subestações, linhas de transmissão, tem-se o mapa perceptual da Figura 4.



Fonte: Resultados originais da pesquisa

Figura 4: Mapa Perceptual da [ACM] da Amostra Para Exemplo de Estudo

Em uma breve análise do mapa, é possível perceber relações importantes entre algumas variáveis, que configuram as situações mais comuns para interrupções no fornecimento de energia elétrica. Vê-se no mapa que os transformadores de distribuição do exemplo da amostra, estão mais vulneráveis a um dia sem descargas elétricas atmosféricas, com rajada de vento calma (velocidade do vento próxima a zero), com uma temperatura média entre 28ºC e 30ºC, e uma chuva fraca (menos de 2,5 mm/h). Mas também interessante notar o quanto uma rajada de vento classificado como Brisa Forte, na Escala de Beaufort, com velocidade do vento acima dos 38Km/h, pode ser mais preponderante a derrubar o sistema elétrico, do que uma chuva moderada.

Entretanto, antes de quaisquer conclusões antecipadas, cabe verificar se as mesmas distâncias se mantêm quando vistas em gráficos de três dimensões. O que pode se tornar um trabalho de rotina a se adotar em uma distribuidora de energia elétrica.

b) Imperatriz

Após a carga dos dados da cidade de Imperatriz, segunda principal cidade do Estado do Maranhão em importância econômica, para efeitos de comparação com os resultados encontrados para a capital do Estado, no início deste trabalho, serão seguidos exatos mesmos procedimentos tomados no estudo anterior. A base de dados correspondente a um ano de informações, sobre todos os transformadores de distribuição instalados, contém 280.442 observações.

Do mesmo modo como aconteceu com os dados da primeira amostra, para o estudo com os dados do município de Imperatriz, a média e a variância da variável dependente INTERRUPCAO encontradas foram respectivamente 0.0056233, e 0.0055917, números muito próximos, que mostram que o diagnóstico preliminar para observação de eventual igualdade,também aponta para um estudo de um fenômeno raro, mais uma vez, corroborando a tese da Distribuição de Poisson como melhor modelo estatístico para esta nova amostra.

Então, como pode ser visto na Tabela 3, também foi aplicado o modelo de Poisson, e já é possível verificar em termos quantitativos, que há menos variáveis de fenômenos meteorológicos se correspondendo com a variável dependente, interrupção no fornecimento de energia, do que na cidade de São Luís, sendo elas as variáveis PLUVIOMETRIA e RAJADA. A primeira se referindo ao volume de chuvas, e a segunda com a força repentina do vento, ambas com p-valor abaixo de 0.05, o que significa são estatisticamente significantes para explicar as interrupções no sistema elétrico, há um nível de significância de 5%.

Outra diferença em relação aos dados de São Luís, é que enquanto no estudo da capital, em que dois tipos de fases da amostra (AC, e B) se mostraram estatisticamente significante para fins preditivos, a um intervalo de confiança de 95%, nenhuma fase da amostra de Imperatriz teve resultado semelhante. Entretanto, vale pontuar que a fase ABC possui uma significância de 10%, enquanto na amostra de São Luís, a mesma não teve significância importante para o modelo estatístico de Poisson.

Já em relação a potência dos transformadores (variável KVA), resultado muito semelhante se obteve ao estudo da amostra de dados de São Luís. Em Imperatriz, praticamente todos os transformadores de distribuição mostraram p-valor abaixo de 0.05, quanto a sua potência, ficando de fora apenas os transformadores com potência de 45kva, apresentando um p-valor igual a 0.16979.

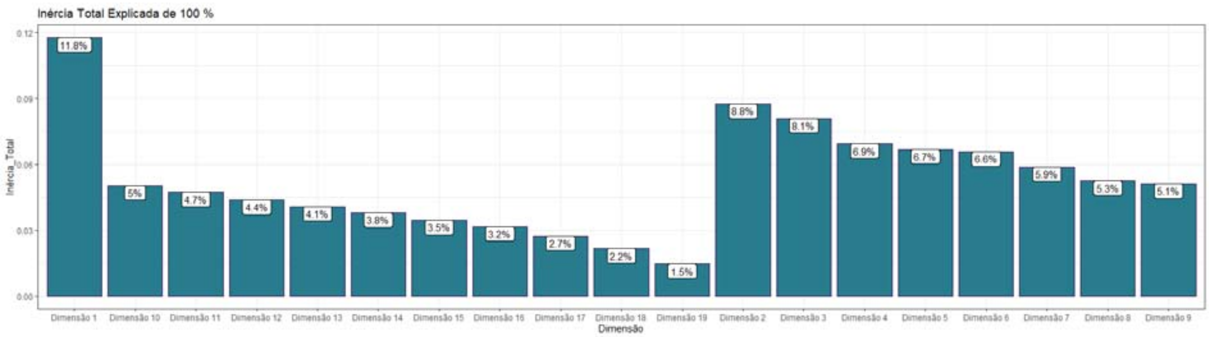
Tabela 3: Summary do Modelo Poisson da base Coletada de Imperatriz

Variáveis	Estimativa	Erro padrão	Valor de Z	Pr(>|z|)
(Intercepto)	-6,6868	0,7542	-8,8660	<2e-16
FASESAB	0,6384	0,4976	1,2830	0,1996
FASESABC	1,1842	0,3659	3,2370	0,0012
FASESAC	0,2637	0,4207	0,6270	0,5308
FASESB	-1,0221	0,4310	-2,3710	0,0177
FASESBC	-0,0565	0,6097	-0,0930	0,9261
FASESC	-0,3513	0,5187	-0,6770	0,4982
KVA10	-3,2960	0,3605	-9,1420	<2e-16
KVA112,5	1,1633	0,1070	10,8690	<2e-16
KVA15	-1,9363	0,2319	-8,3490	<2e-16
KVA150	1,3345	0,1307	10,2060	<2e-16
KVA1500	-4,8743	1,0207	-4,7760	0,0000
KVA2000	-4,8743	1,0207	-4,7760	0,0000
KVA225	-2,3017	0,3194	-7,2070	0,0000
KVA30	-2,2306	0,3216	-6,9370	0,0000
KVA300	-3,4830	0,5302	-6,5690	0,0000
KVA3500	-4,8708	1,0162	-4,7930	0,0000
KVA45	-0,2392	0,1742	-1,3730	0,1698
KVA5	-2,6783	0,2943	-9,1000	<2e-16
KVA500	-3,2648	0,4937	-6,6130	0,0000
KVA600	-4,8743	1,0207	-4,7760	0,0000
KVA75	0,9328	0,1065	8,7580	<2e-16
MEDIA_CLIENTES	-0,0002	0,0014	-0,1340	0,8931
PLUVIOMETRIA	0,0083	0,0020	4,2340	0,0000
TEMP_MIN	0,0273	0,0222	1,2250	0,2204
TEMP_MAX	0,0311	0,0203	1,5300	0,1261
TEMP_MEDIA	-0,0253	0,0387	-0,6530	0,5137
DESCARGAS_ATM	-0,0010	0,0015	-0,6320	0,5275
RAIO	0,0320	0,1190	0,2690	0,7878
RAJADA	0,0163	0,0029	5,5700	0,0000
VENTOS_KMH	-0,0085	0,0044	-1,9390	0,0525

Fonte: Resultados originais da pesquisa

Também, para fins de comparação com o estudo anterior, o mesmo exemplo de "predict" feito para a mostra de São Luís, foi feito para a amostra de Imperatriz, com as mesmas variáveis, e o resultado foi bem diferente entre as duas cidades. Enquanto a probabilidade de uma interrupção no fornecimento de energia elétrica na primeira amostra foi de 36,6%, nas mesmas condições do tempo, e mesmas características de transformadores, o resultado foi uma probabilidade de apenas 5,16% do sistema elétrico ser interrompido pelos mesmos fatores (sete vezes menor).

Ao realizar a análise de correspondências múltiplas, mais diferenças são observáveis entre os dois resultados. Em razão das disparidades climáticas entre as duas cidades, mais categorias foram adicionadas para os cálculos, gerando 19dimensões para a análise, três dimensões a mais que na amostra de São Luís, conforme o Figura 5, com a inércia total explicada da análise de correspondência múltipla.



Fonte: Resultados originais da pesquisa

Figura 5: Inércia Total Explicada da [ACM] da Amostra (Imperatriz) -

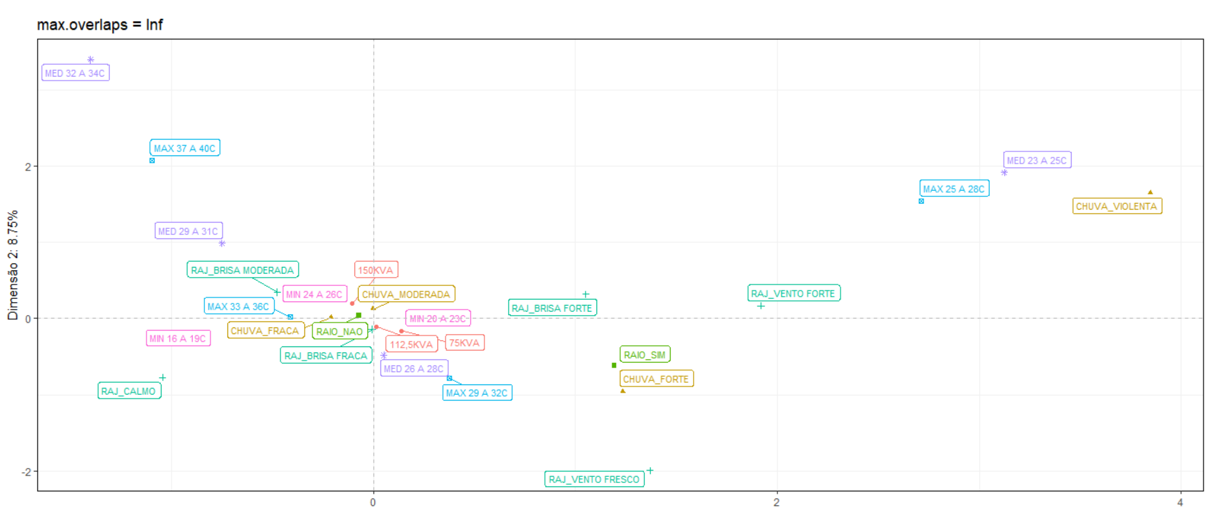
Assim como é minuciosamente explicado pelo site Weathers Park (2022), São Luís e Imperatriz possuem grandes diferenças de temperatura ao longo do ano, tendo Imperatriz como cidade com temperaturas mínimas registradas menores que a capital do Estado, e as temperaturas máximas registradas maiores que São Luís.Ainda de acordo com Weathers Park, há diferenças importantes quanto a velocidade dos ventos. São Luís rotineiramente registra maiores velocidades dos ventos do que na cidade de Imperatriz como descrito no referido portal.

De acordo com Lima e Ferreira (2013), separadas por aproximadamente 600km, uma da outra, as duas cidades de fato possuem climas bastante divergentes. São Luís, que fica ao norte do Estado, é uma cidade litorânea, mais sujeita a ventos fortes, e temperaturas mais equilibradas ao longo do ano, do que a cidade de Imperatriz, ao sul, com um tipo de clima misto, ora seco como o cerrado e ao sertão, ora chuvoso como o clima amazônico, por fazer fronteira entre estes dois biomas, além de ventos mais fracos, e temperaturas mais extremas do que na capital.

Ao analisar o mapa perceptual da amostra de Imperatriz na Figura 6, é interessante perceber que a chuva violenta (com mais de 50mm/h) tem pouquíssima relação com as interrupções no fornecimento de energia de Imperatriz. Isto pode mostrar o quanto o sistema elétrico na região foi bem preparado pela distribuidora para suportar as fortes intempéries do período chuvoso.

Já a chuva moderada (entre 2,5 a 10 mm/h) se mostra muito mais relevante para a interrupção do fornecimento de energia do que em São Luís. A rajada de brisa forte, que em São Luís se mostra importante, em Imperatriz é a rajada de brisa fraca (ventos repentinos de 12 a 19km/h) que se mostra mais preponderante.

Tal mapa pode auxiliar as áreas de engenharias a encontrar soluções que mitiguem a quantidade de suspensões do fornecimento de energia elétrica, segundo as condições apresentadas.



Fonte: Resultados originais da pesquisa

Figura 6: Mapa Perceptual da [ACM] da Amostra Para Exemplo de Estudo (Imperatriz)

V. Conclusão

É possível afirmar, através deste trabalho de pesquisa realizado com dados reais de uma distribuidora de energia elétrica do Estado do Maranhão, com duas de suas principais cidades, que há de fato, com um nível de significância de 5%, fortes correlações associadas aos fenômenos meteorológicos e as interrupções no fornecimento de energia, com causas desconhecidas, para ambas as amostras, com ressalvas que indicam que o estudo precisa ser de fato específico por região, e que, para fins preditivos, o modelo de distribuição de Poisson se encaixa perfeitamente.

Ainda, o estudo possibilita às distribuidoras, que possam trabalhar de modo preventivo, identificando as fragilidades do sistema elétrico quanto ao tema, e explorar ações que possam reduzir a frequência com que acontecem as interrupções, analisando não só transformadores de distribuição, mas equipamento por equipamento, ou até mesmo estruturas mais robustas, como subestações, através modelo de Poisson, e de mapas perceptuais de análise de correspondência múltipla, de modo a melhor o indicador do [FEC].

Por fim, também é possível criar um sistema de alertas que envie para o Centro de Operações Integradas, que tipo de equipamento, onde, e a que probabilidade, este possa ter sua distribuição de energia interrompida, de acordo com a previsão do tempo, combinado ao Sistema de Monitoramento de Alertas do ClimaTempo, com previsões em tempo real, podendo antecipadamente ao fenômeno,deslocar equipes de plantão a lugares estratégicos, para que estas possam tomar ações que reestabeleçam o fornecimento de energiacom mais celeridade. Desta forma, melhorando também o indicador do [DEC].

Por fim, este estudo sugere que outras variáveis sejam acrescentadas para um estudo semelhante, como a vida útil da rede, transformador de distribuição, ou o que queira ser estudado. Também seria interessante acrescentar o fabricante, e lote adquirido, para identificar se uma linha de materiais comprados pela distribuidora não possui mais fragilidade à fenômenos meteorológicos.

Agradecimento

A Deus por ter me dado toda a força deste mundo para chegar até aqui, com tantas pedras pelo caminho, incertezas que quase me levaram a desistir, dificuldades financeiras, mas principalmente a difícil arte de revezar o tempo com a família, amigos e trabalho, tarefa das mais complicadas que já passei nos últimos tempos. Só eu e Ele sabíamos o que estávamos construindo. Agradecer em especial aos amigos Evandro Lima Meireles, da Gerência Corporativa de Geoprocessamento, e Eliezer Silva de Oliveira, da Gerência Corporativa de Operações, que com seus esforços na fase de mineração de dados, contribuíram enormemente com este trabalho, além também das pessoas que de alguma forma compreenderam este projeto de vida, e minimamente colaboraram para a conclusão deste trabalho.

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Apêndice: Operações utilizadas no R Studio para a realização deste estudo

Base de informações do município de São Luís

```
> glimpse(base_slz) #visualização das observações e das  especificações
Rows: 272,151
Columns: 14
$ INTERRUPCAO    <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
$ FASES          <chr> "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", "AB~
$ KVA            <chr> "0", "112,5", "112,5", "0", "0", "112,5", "112,5", "75", "1~
$ MEDIA_CLIENTES <dbl> 193, 68, 90, 151, 149, 131, 156, 207, 116, 288, 230, 108, 3~
$ PLUVIOMETRIA   <dbl> 0.234375, 0.234375, 0.234375, 0.234375, 0.234375, 0.234375,~
$ TEMP_MIN       <dbl> 24, 24, 24, 24, 24, 24, 24, 24, 24, 24, 24, 24, 24, 24, 24,~
$ TEMP_MAX       <dbl> 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32,~
$ TEMP_MEDIA     <dbl> 28.0, 28.0, 28.0, 28.0, 28.0, 28.0, 28.0, 28.0, 28.0, 28.0,~
$ DESCARGAS_ATM  <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
$ RAIO           <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
$ RAJADA         <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
$ VENTOS_KMH     <dbl> 18.72, 18.72, 18.72, 18.72, 18.72, 18.72, 18.72, 18.72, 18.~
```

Estimação do modelo Poisson para São Luís

```
##################################################################################
#                          ESTIMAÇÃO DO MODELO POISSON                           #
##################################################################################
#Estimação do modelo
modelo_poisson <- glm(formula = INTERRUPCAO ~ FASES + KVA
                      + MEDIA_CLIENTES + PLUVIOMETRIA + TEMP_MIN
                      + TEMP_MAX + TEMP_MEDIA + DESCARGAS_ATM
                      + RAIO + RAJADA + VENTOS_KMH
                      ,
                      data = base_slz,
                      family = "poisson")
```

Probabilidade de interrupção de energia em condições hipotéticas em São Luís

```
> #Modelo Poisson:
> predict(object = modelo_poisson2,
+         newdata = data.frame(INTERRUPCAO = 1,
+                              FASES = "ABC",
+                              KVA = "112,5",
+                              PLUVIOMETRIA = 15,
+                              TEMP_MIN = 22,
+                              RAIO = 1,
+                              RAJADA = 30),
+         type = "response")
        1
0.3657294
```

Amostra de dados para Análise de Correspondência Múltipla de São Luís

```
> base_slz_anacor <- read_excel("base_sao_luis_anacor.xlsx")
> glimpse(base_slz_anacor)
Rows: 3,076
Columns: 8
$ FASES          <chr> "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", "ABC", ~
$ KVA            <chr> "112,5KVA", "75KVA", "75KVA", "112,5KVA", "112,5KVA", "75KVA", "150KVA~
$ PLUV_TIPO      <chr> "CHUVA_FRACA", "CHUVA_FRACA", "CHUVA_FRACA", "CHUVA_FRACA", "CHUVA_FRA~
$ TEMP_MIN_FAIXA <chr> "MIN 25 A 26C", "MIN 25 A 26C", "MIN 25 A 26C", "MIN 23 A 24C", "MIN 2~
$ TEMP_MAX_FAIXA <chr> "MAX 32 A 34C", "MAX 32 A 34C", "MAX 32 A 34C", "MAX 29 A 31C", "MAX 2~
$ TEMP_MED_FAIXA <chr> "MED 28 A 30C", "MED 28 A 30C", "MED 28 A 30C", "MED 25 A 27C", "MED 2~
$ RAIO           <chr> "RAIO_SIM", "RAIO_SIM", "RAIO_SIM", "RAIO_SIM", "RAIO_SIM", "RAIO_SIM"~
$ RAJADA_TIPO    <chr> "RAJ_CALMO", "RAJ_CALMO", "RAJ_CALMO", "RAJ_CALMO", "RAJ_BRISA FORTE",~
>
```

Base de informações do município de Imperatriz

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> glimpse(base_itz) #Visualização das observações e das  especificações
Rows: 280,442
Columns: 12
$ INTERRUPCAO    <dbl> 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0~
$ FASES          <chr> "ABC", "ABC", "A", "A", "A", "AB", "AB", "ABC", "ABC", "ABC", "ABC", "~
$ KVA            <chr> "75", "225", "10", "15", "5", "10", "5", "0", "10", "112,5", "15", "15~
$ MEDIA_CLIENTES <dbl> 6, 163, 2, 9, 2, 6, 14, 137, 0, 161, 78, 196, 1, 1, 42, 25, 27, 19, 55~
$ PLUVIOMETRIA   <dbl> 0.0, 0.0, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, 0.6, ~
$ TEMP_MIN       <dbl> 16.7, 16.7, 21.9, 21.9, 21.9, 21.9, 21.9, 21.9, 21.9, 21.9, 21.9, 21.9~
$ TEMP_MAX       <dbl> 35.8, 35.8, 31.6, 31.6, 31.6, 31.6, 31.6, 31.6, 31.6, 31.6, 31.6, 31.6~
$ TEMP_MEDIA     <dbl> 25.4, 25.4, 24.6, 24.6, 24.6, 24.6, 24.6, 24.6, 24.6, 24.6, 24.6, 24.6~
$ DESCARGAS_ATM  <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0~
$ RAIO           <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0~
$ RAJADA         <dbl> 20.2, 20.2, 20.2, 20.2, 20.2, 20.2, 20.2, 20.2, 20.2, 20.2, 20.2, 20.2~
$ VENTOS_KMH     <dbl> 14.8, 14.8, 14.8, 14.8, 14.8, 14.8, 14.8, 14.8, 14.8, 14.8, 14.8, 14.8~
>
```

Probabilidade de interrupção de energia em condições hipotéticas em Imperatriz

```
> #Modelo Poisson
> predict(object = modelo_poisson2,
+         newdata = data.frame(INTERRUPCAO = 1,
+                              FASES = "ABC",
+                              KVA = "112,5",
+                              PLUVIOMETRIA = 15,
+                              TEMP_MIN = 22,
+                              RAIO = 1,
+                              RAJADA = 30),
+         type = "response")
         1
0.05156898
```

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Fusion Reactor, Having Several Chambers for Synthesis, Operating by Turns

By Victor A. Dubrovsky

Abstract- Work on creating a thermonuclear fusion reactor, which began more than half a century ago, has not yet led to the development of a continuous reactor design. The reason for this is the orientation of all teams developing reactors to use one chamber where the reaction occurs. With the arrangement, no materials or cooling schemes can withstand the super-solar temperatures required to achieve fusion. An engineering solution to the problem has been proposed: the use of several synthesis chambers operating alternately. Some details of this reactor layout are considered.

GJRE-F Classification: LCC: QC791.75

FUSIONREACTORHAVINGSEVERALCHAMBERSFORSYNTHESISOPERATINGBYTURNS

Strictly as per the compliance and regulations of:

Fusion Reactor, Having Several Chambers for Synthesis, Operating by Turns

Victor A. Dubrovsky

"You are going to die, but sow rye..."
Russian proverb

Abstract- **Work on creating a thermonuclear fusion reactor, which began more than half a century ago, has not yet led to the development of a continuous reactor design. The reason for this is the orientation of all teams developing reactors to use one chamber where the reaction occurs. With the arrangement, no materials or cooling schemes can withstand the super-solar temperatures required to achieve fusion. An engineering solution to the problem has been proposed: the use of several synthesis chambers operating alternately. Some details of this reactor layout are considered.**

I. The State of Art

More than half a century ago, the work began aimed at creating a reactor for thermonuclear fusion, promising the prospect of energy production unprecedented in scale and simplicity.

Since then, work carried out in several countries has not resulted in the creation of a continuously operating reactor, but has expanded knowledge of the synthesis process and its effect on structural materials. And the main result of obtaining this knowledge today is the awareness of the fact that no materials and no cooling schemes can withstand the super-solar temperatures necessary for fusion for a long enough time.

Over the past years, various compositions and physical states of reagents, various systems for the formation and retention of plasma formed during fusion, and various schemes for realizing the energy generated during fusion have been proposed.

Today it is possible to summarize the data on the layout of the synthesis reactor as a system.

The reactor as a system consists of the following subsystems:

- The control subsystem;
- The device for dosing reagents and supplying them to the volume where synthesis is carried out (all studied reactor schemes provide for discrete supply of reagents and carrying out the synthesis reaction);
- The synthesis initiation subsystem;
- The subsystem for the formation and retention of plasma generated as a result of synthesis;
- The volume in which synthesis is realized;
- The cooling subsystem of this volume;
- The plasma transportation subsystem;
- The subsystem for utilization of energy generated during synthesis. This can be either a transformer that converts the pulsating current obtained when plasma passes through a magnetic field into alternating current, or a steam generator that converts the heat of the plasma into steam energy, which is subsequently used to produce electricity in a steam turbine generator.

For example, the reagents are fed into the synthesis chamber in the form of tablets, and the fusion energy is converted into electricity when the plasma passes through a magnetic field.

II. The Main Problem and the Way to Solve It

It is important to note that all reactor layouts proposed today have one thing in common: each reactor has a single synthesis chamber, in which synthesis is carried out with discrete supply of portions of reagents.

It turned out that no materials and no cooling systems can ensure sufficiently long (more than tens of seconds) operation of the synthesis chamber.

To solve this problem, it is proposed to replace the single synthesis chamber (for any set of other reactor subsystems) with several smaller chambers operating in turn. After a single implementation of synthesis in each specific chamber, it is cooled to temperatures that allow the next synthesis to be carried out, and further synthesis is carried out in turn in the remaining chambers, which will ensure the continuity of energy generation by the reactor.

The number of chambers will be determined in such a way that each chamber has time to cool down to acceptable temperature levels while the synthesis is implemented one by one in the remaining chambers.

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III. Proposed Reactor Layout

The layout is shown schematically in Fig. 1.

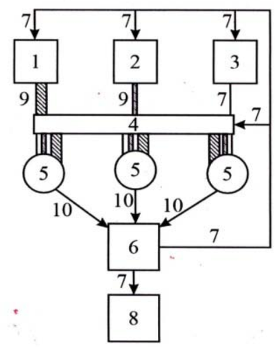

Fig. 1: Scheme of Composition of the Proposed Reactor

Here: 1 – container with reagents, 2 – energy source for starting the reaction, 3 – cooling system, 4 – control unit, 5 – chambers that make up the reactor, 6 – final energy device (steam generator or electrical transformer), 7 – channel energy supply, 8 – energy consumers, 9 – channels for supplying reagents and cooling, 10 – channels for removing energy from the chambers that make up the reactor.

Each reactor chamber can be spherical; it is assumed that the mixture of reagents is pulsed through the input channel under maximum pressure, into a spherical sub-chamber of the minimum required diameter, "ignited" at the moment of maximum pressure, while the plasma will generate an instantaneous pulse of electric current or will enter the steam generator.

In practical implementation, the number of sub-chambers that make up the reactor and the volume of each sub-chamber will be determined by the required generator power and the achievable cooling intensity.

Let me remind you that even today the supply of reagents in reactors of all types occurs discretely, i.e. the same can be applied when feeding reagents into several chambers in turn.

It is clear that each fusion chamber must have its own plasma retention system and a system for its evacuation after the reaction. When using the conversion of plasma energy into a pulsating electric current in each of the chambers that make up the reactor, the final energy output will be an electrical transformer; when using energy conversion through a steam generator, the energy output will be a steam turbine generator.

It should be noted that thermonuclear fusion has no lowest limit on the volume of the reactant. This opens up great prospects for the creation of minimal sized reactors for use, including at ships firstly. The miniaturization of reactors is also facilitated by the fact that, as far as the author knows, thermonuclear fusion is not accompanied by the generation of intense penetrating radiation of any kind, i.e. the dimensions and weight of the biological protection of reactors can be minimal.

In addition, an emergency interruption of a fusion reactor cannot cause its destruction, so a fusion reactor is, in principle, safer than other types of nuclear reactors.

It must be emphasized once again that several alternately operating fusion chambers can be used with any type of reagents, any schemes for initiation and retention of plasma, and any form of utilization of generated energy.

IV. An Organization Note

It can be assumed that at the moment all the teams involved in the problem under consideration have long-term plans for allocations for relevant research. Let me emphasize: only for research, since none of the fusion reactor options being studied today provides the creation of an energy source that is operational for a long time.

Therefore, one can expect great difficulties in implementing the proposed option.

In this regard, it seems advisable to order the implementation not from a university or research center, but from a large production association, providing it with the opportunity to attract specialists from the relevant branches of science.

At the same time, it is obvious that the main difficulties will be in terms of engineering implementation, first of all, in creating the most efficient cooling system and accurately determining the required cooling time for each given power of the designed reactor.

Literature

Application for a patent No. 2023103456 Institute of Innovation and Law, author – Dubrovsky V. A.

Viktor Anatoly Dubrovsky Dr. Scs., Dr. Phil.

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The Future Grid in a Dynamic Spiral

By Alexandre Pavlovski

Abstract- Energy Transition from fossil fuel derived power sources to that of clean, renewably sourced, electricity enabling total electrification has emerged as the overriding challenge for humankind in the first quarter of the 21st century. Ensuring energy security, adapting to climate change, and embracing the low carbon economy were among the critical factors for this paradigm shift. "Soft revolutions" in renewable generation, battery storage, and power electronics, technologically enabled the energy transition to clean electricity.

A pivotal advance in total electrification of our society, empowering the electricity value chain, is propelling the rapid transformation of the existing power grid into the "Future Grid". This global, evolutionary, development based on a combination of techno-economical and psycho-social understanding of electricity systems is seen as an absolute priority target in the current decade. An expected goal and result of this development is that alternate current (AC)/direct current (DC) grids merge.

Keywords: climate change adaptation, low carbon economy, energy security, energy transition, electricity value chain, future grid, alternate current/direct current grid merge, spiral dynamics integral.

GJRE-F Classification: LCC Code: TK1001-1841

THEFUTUREGRIDINADYNAMICSPIRAL

Strictly as per the compliance and regulations of:

The Future Grid in a Dynamic Spiral

Alexandre Pavlovski

Abstract- Energy Transition from fossil fuel derived power sources to that of clean, renewably sourced, electricity enabling total electrification has emerged as the overriding challenge for humankind in the first quarter of the 21st century. Ensuring energy security, adapting to climate change, and embracing the low carbon economy were among the critical factors for this paradigm shift. "Soft revolutions" in renewable generation, battery storage, and power electronics, technologically enabled the energy transition to clean electricity.

A pivotal advance in total electrification of our society, empowering the electricity value chain, is propelling the rapid transformation of the existing power grid into the "Future Grid". This global, evolutionary, development based on a combination of techno-economical and psycho-social understanding of electricity systems is seen as an absolute priority target in the current decade. An expected goal and result of this development is that alternate current (AC)/direct current (DC) grids merge.

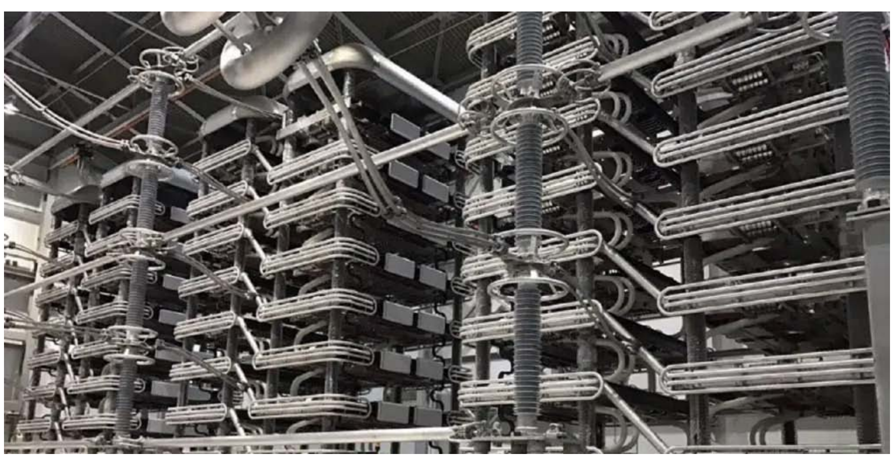
A strong leap to AC/DC grid merge is presented by the deployment of low voltage and medium voltage DC grids, and development and manufacturing of Grid Forming converters to connect to and support AC grids. Immediate steps in paving the way for the Future Grid are being promptly taken to develop, coordinate, and approve, requirements to grid codes for DC grids and Grid Forming converters. They show today's ability to meet the Future Grid target demonstrated by technical, business and research expertise.

The significance of the Future Grid with the AC/DC grids merge as its core, and related commitments of society are also very important for the broader societal goals addressing low carbon economy and sustainability, such as many of the United Nations' Sustainable Development Goals.

To ensure that timely coordination of the government, academic, private, and civil sectors of society on multiple levels to achieve AC/DC grid merge is in place within the timeframe required by a goal of 100% clean electricity by 2035, socio-psychological tools engaging all the four sectors should be considered. Spiral Dynamics Integral (SDi) methodology and practice ensuring constructive dialogue and cooperative action is recommended to address problems and solutions of the AC/DC grid merge. Readers are warmly encouraged to explore the SDi conceptual framework to map and address complex challenges presented by the AC/DC grid merge, and develop a new view on organizations and people involved to optimally and effectively align their versatile needs.

Keywords: climate change adaptation, low carbon economy, energy security, energy transition, electricity value chain, future grid, alternate current/direct current grid merge, spiral dynamics integral.

Graphic Abstract



I. Introduction

a) Accelerating Total Electrification

Electricity is becoming the key fuel for human activities, and total electrification covering all areas of life is understood as inevitable. Changes in the world clearly show that human practices are more and more "electrified" [1]. While there are major differences between urban and rural areas and the degree of electrification worldwide, access to electricity is considered one of the prerequisites for a contemporary life.

Between 1980 and 2022, electricity consumption more than tripled, reaching approximately 25,500 terawatt-hours in 2022, and 91.2% of the world population in 2022 had access to electricity. As more energy end uses become electrified, the share of electricity in total final energy consumption is expected

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to grow from 20% in 2022 to over 27% in 2030 (see the Net Zero Emissions by 2050 Scenario [1]).

Energy Transition from fossil fuel derived power sources to that of clean, renewably sourced electricity, enabling total electrification, has emerged as the overriding challenge for humankind in the first quarter of the 21st century [2-8]. Ensuring energy security [9-16], adapting to climate change [17-21] and embracing the low carbon economy [22,23] were among the critical factors for this paradigm shift.

Based on the wide availability and maturity of renewable technologies, investments in renewables globally in 2022 reached a record high of $1.3 trillion, a 19% increase from 2021 investment level. To continue increasing the supply of clean energy and its associated technologies, the innovation landscape of clean energy solutions must be boosted [2].

b) Why the Future Grid?

The key driver of Energy Transition, sometimes hidden behind global economic and political implications, balancing energy security, equity, and resilience, is the electricity grid. Often called power grid, it empowers the electricity value chain.

Ensuring clean electrification targets are achieved globally means power grids must be promptly brought to a new, much higher, level of complexity. They must meet a 21st century definition of the Future Grid as a seamless, flexible, cost-effective electricity system. Leading jurisdictions globally are continuously upgrading the leading role of the Future Grid as the energy transition driver [24,25].

The huge need for and acceleration towards the Future Grid as a macro-scale human development require high-pace transformational efforts. These efforts are needed for promptly establishing practices and experiences based on a combination of techno-economical and psycho-social understanding of electricity systems. This evolutionary Future Grid development calls for unique approaches and solutions such as the Alternate Current (AC)/Direct Current (DC) Grid Merge. It also calls for constructive dialogue and cooperative actions of the government, academic, private, and civil sectors of society to coordinate their Future Grid efforts and achievements.

c) Why a Dynamic Spiral?

To ensure timely coordination of all the four sectors on multiple levels, socio-psychological tools may be required. One example of internationally tested toolsets addressing geopolitical, economic, social and technical aspects of macro-scale human developments in the society that may be considered for supporting a decentralized, decarbonized and digitalized Future Grid development is Spiral Dynamics Integral [26-29].

Spiral Dynamics Integral (SDi) is a theoretical and practical model for understanding and operating based on dynamic forces in human-made developments and change processes, often macro-scale. SDi uses a conceptual framework to map complex human issues and develop a new view on society, organizations and people. SDi concepts are focused on understanding the versatile needs of individuals, groups, organizations and society, and on aligning them in the most optimal and effective way.

The Future Grid development and unfolding AC/DC Grid Merge is a macro-scale human-based undertaking. This development started in the late 19th century, and moved in a spiral of thinking and doing to greater complexities. The timeliness of this development calls for SDi skills contributing to and supporting the low carbon economy.

The major objectives of this paper are as follows:

- Manifest the urgency of the Future Grid development for Energy Transition.
- Validate and defend the ability of electrical systems for AC/DC Grids Merge.
- Show the Future Grid solutions addressing the needs and complexities of the electricity value chain.
- Demonstrate available socio-psychological tools such as Spiral Dynamics Integral for supporting and leveraging the AC/DC grids merge.
- Analyse the current state of conditions for change in the AC/DC grids merge.
- Highlight the knowledge gap in initial requirements for the AC/DC grids merge.

The paper brings to the readers attention solutions and opportunities for power grids experiencing a Dynamic Spiral of changes. It refers to the history of the power grid, considers current developments, and defines the leadership needs to accelerate the global development of the Future Grid. Based on the insights shared, the paper makes a call for constructive dialogue and cooperative actions of the government, academic, private, and civil sectors of society accelerating the AC/DC grids merge.

II. Materials and Methods

a) Future Grid for Energy Transition

"How feasible is the transition to net zero?...

The core will be to electrify everything and simultaneously develop green electricity."

Mark Carney[1]

Global electrification is inevitably and meaningfully changing the ways we live, and clean, renewably sourced, electricity is making it possible. The only way to sustain this change is to promptly re-engineer the existing power grid into the Future Grid, addressing our needs and daily experiences. Let us look attentively at the drivers of this transition.

[1] Carney, M. (2021). Value(s): Building a Better World for All. William Collins.

i. *Total Electrification: A Must*

When thinking about electricity, we rarely connect things like Energy Security, Climate Change Adaptation and the Low Carbon Economy. They may seem unattached to our daily lives. However, these sustainable cultures and forces embedded in all our human practices have been changing our lives and helped us achieve our goals and survive as society.

a. *Energy Security*

An understanding of Energy Security is more and more felt as a part of personal and collective life. We cannot live without energy security in very "simple" things such as driving cars or maintaining thermal comfort in our homes. It ensures availability, accessibility, affordability, and acceptability of energy [12] and touches Physical and Economical Security, and Environmental Sustainability. It also addresses technical issues such as reliability, resilience, & efficiency [9], as well as emergency response policies and practices ensuring "the uninterrupted availability of energy sources at an affordable price" [13].

As a complex concept, Energy Security is well defined as "equitably providing available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users" [30,31]. As a holistic concept, sometimes it is presented as an "antipode" of "vulnerability of vital energy systems" [10] or "energy poverty" [32-36].

To better understand, compare and upgrade the Energy Security of households, businesses, communities or jurisdictions, a comprehensive multi-dimensional Energy Security Index was developed. This Index was based on responses from a broad group of stakeholders (including civil society, academics, government and private sectors) addressing the practical usability of Energy Security dimensions and metrics [31]. The Energy Security Index presents the following dimensions and related components:

- Availability: Security of supply, Production, Dependency, and Diversification
- Affordability: Stability, Access, Equity, and Affordability
- Technology development and efficiency: Innovation and research, Energy Efficiency, Safety and Reliability, and Resilience
- Environmental sustainability: Land use, Water, Climate Change and Pollution
- Regulation and governance: Governance, Trade and Connectivity, Competition and Information

An increase in electrification at household, community/neighbourhood, municipality, county/territory, province/state and country levels for residential, commercial, institutional, and industrial electricity uses increases the Energy Security rating for each of these key dimensions, and the overall Energy Security rating as well as the related Quality of Life rating.

b. *Climate Change Adaptation*

Climate change adaptation means adjusting economic, ecological and social systems, practices and ways of life to an actual and expected future climate [17-19]. We need to reduce our risks from the harmful effects of climate change such as more intense extreme weather events, sea-level rise, or food insecurity. We also need to address any potential beneficial opportunities associated with climate change (e.g., longer growing seasons or increased yields); countries and communities are required to develop adaptation solutions and implement actions to respond to current and future climate change impacts, and do it at local scale.

Continuing adaptation to the Climate Change spiral [19] includes planning for adaptation, implementing adaptation measures, assessing impacts, vulnerability and risks, and monitoring and evaluating adaptation.

As a critical part of economic systems, an electricity system has to harden and back up infrastructure against increasingly severe and frequent weather events, to limit their cascading impacts in the electricity value chain [20], as the costs of inaction will exceed the costs of adaptation [21].

c. *Low Carbon Economy*

A low-carbon economy is based on energy sources producing low levels of greenhouse gas emissions [22]. Any product, service or solution in the economy has its own Carbon Life Cycle [23]. The carbon life cycle components include embodied carbon (carbon content of all the materials used in the solution, including manufacturing and processing, transportation, delivery, and installation), operating carbon (required for operations, maintenance, and upgrades), and recycling.

Each of the carbon life cycle components uses energy from energy sources available. Reducing greenhouse gas emissions by choosing lower carbon energy sources is seen by society as one of the most important actions required to mitigate climate change. The low carbon economy makes clean electricity the energy source of choice.

Looking into electrification as a result of Energy Security, Climate Change Adaptation and Low Carbon Economy efforts, we see the role of electricity in the 21st century completely changing. Making electricity a 100% Primary Fuel for all areas of economic activity is changing the electricity value chain, and low carbon electricity is paving the way of energy transition.

ii. *Energy Transition – the Time Has Come*

Diversification of electricity sources and scaling the growth of clean electricity historically started in the late 20th century by wind power and was promptly followed in 2000s by solar photovoltaics. With wind and solar joining hydro, clean electricity moved from its "secondary" to "primary" role as an energy source clearly competing with fossil fuels like coal and oil (and later – natural gas) and moving these fossil fuels to other economic applications.

The increasing penetration of renewable energy into the energy supply mix, towards total electrification, is very often referred to as an "energy transition" [2-7, 24, 25]. This sustainable energy transition refers to the global energy sector's shift from fossil-based to renewable energy sources with their systemic integration and related reduction of greenhouse gas emissions.

Access to electricity from renewable sources at any spatial level (household, neighbourhood, municipality, county/territory, province/state or country) today brings significant changes in the electricity value chain, including generation, transmission, distribution, storage and consumption [37-44]. It strengthens the core foundation of sources for energy security and supports the Low Carbon Life Cycle and Climate Change Adaptation objectives.

iii. *Inevitable Leap to Future Grid*

The significant changes in each of the links of the electricity value chain - from electricity generation via transmission and distribution to electricity consumption - are shaped by "soft revolutions" at the end of 20th century in the two key areas: Power Electronics and Battery Storage. Technologies and advancements in both areas allowed for changing the major tool of energy transition – power grids, covering every clean electricity hub – from renewable power plants and transmission and distribution substations to service transformers in feeders. A dramatic growth of solar PV roofs and electric vehicles in 2010's changing electricity loads added significant changes to operating conditions of the grid. It also showed that an inevitable leap will have to be done in power grid architecture and infrastructure to have successful energy transition happen. Even more, this leap will bring a merge of alternate current-based and direct current-based grids: "The AC/DC war is over, today DC and AC co-exist in Generation, Transmission and Distribution"[52]. The AC/DC merge at the end point of this leap in energy transition was pictured as the grid of the future, or Future Grid. The Future Grid vision spearheaded human thinking as this future had to be reached very soon, in the timeframe required by a goal of 100% clean electricity by 2035– within one human generation.

b) *AC/DC Merge: "Rescuing" the Grid*

"The Grid as a Hostage of Its History"
Mark Ahlstrom[2]

To understand the proposed vision and thinking of the Future Grid evolution, we refer to a very thoughtful definition of the "grid of today" by Mark Ahlstrom, VP Renewable Energy Policy, NextEra Energy Resources: "The Grid as a Hostage of Its History" [45].

Indeed, for people deeply involved in the understanding, deployment and operations of clean electricity solutions in the grid, it is clear that high penetration of these solutions in AC grid has been experiencing and demonstrating a huge roadblock in interconnection to and operations of the grid, and that it requires a large upgrade of the grid infrastructure and functionality.

Clean electricity generation owners/operators are ready and strongly willing to bring power to the grid.

Utilities are interested in and committed to managing clean electricity in the grid.

End users love to use clean electricity in their work and personal life.

However, the process of interconnection and operational control of clean electricity resources is slow and is creating large interconnection queues [46]. The history of the grid brought it very close to a "dead-end" where clean electricity resources are available but cannot be appropriately "absorbed" by the grid. With key limitations in clean electricity transmission and distribution the grid is felt as a "hostage" of its historic AC-based architecture and infrastructure.

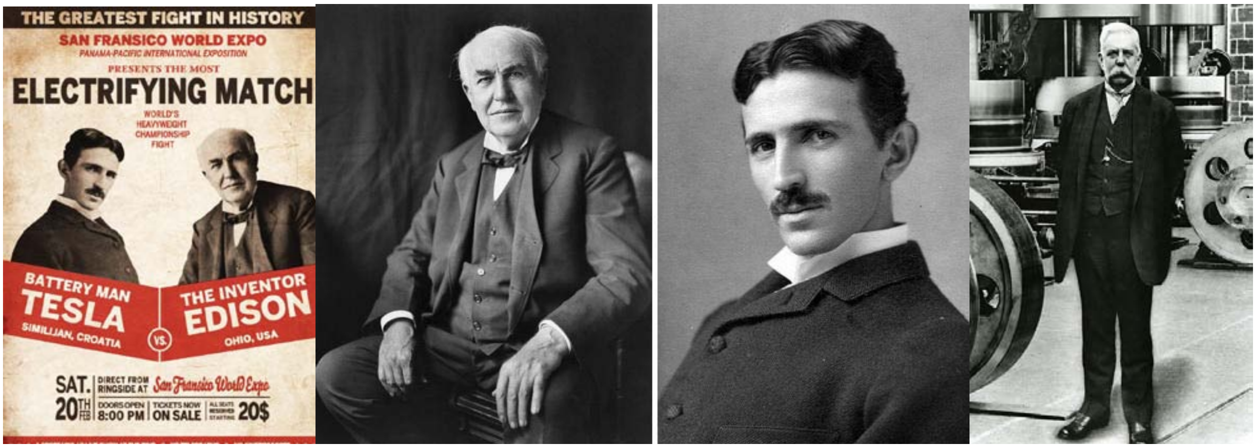
i. *Where Grid History Started*

To accept the hostage nature of the grid in today's 2020's, we have to remember that the "War of the Currents" started in the late 1880's by two inventors and electricity thought leaders in the U.S. - Thomas Edison and Nikola Tesla. In this "war" of intellects, business approaches and Intellectual properties Edison strongly promoted Direct Current (DC), and Tesla - Alternating Current (AC) to transmit electricity in the grid [47-49].

Two major events in 1890's changed the grid's history:

- In 1893 the Westinghouse Corporation illuminated the Chicago World's Fair in 1893 using Tesla's AC generators driven by steam engines (George Westinghouse purchased many of Tesla's patents in 1877).
- In 1895 AC generators designed and built using Tesla's patents were installed by Westinghouse at the hydropower station at Niagara Falls, and the first power was brought to Buffalo in November 1896 – followed by power lines bringing electricity to New York City [50,51].

[2] UWECEmedia. (2019b, May 29). Low inertia PGW2019 - Ahlstrom [Video]. YouTube. https://www.youtube.com/watch?v=aIAaYvN6Nvg



Credits: Sharon Donahue and Library of Congress

Figure 1: Electrification Match: Thomas Edison vs Nicola Tesla + George Westinghouse

"The War of the Currents" defined a very practical need to reduce grid circuit heat losses and supported the final choice for the AC grid concept: Tesla's ingenuity allowed for an opportunity to increase voltage in the grid and reduce the circuit losses and related power costs by using AC transformer technology.

As a result, for over 125 years society has been mostly focused on AC grid architecture and practices in generation, transmission and distribution.

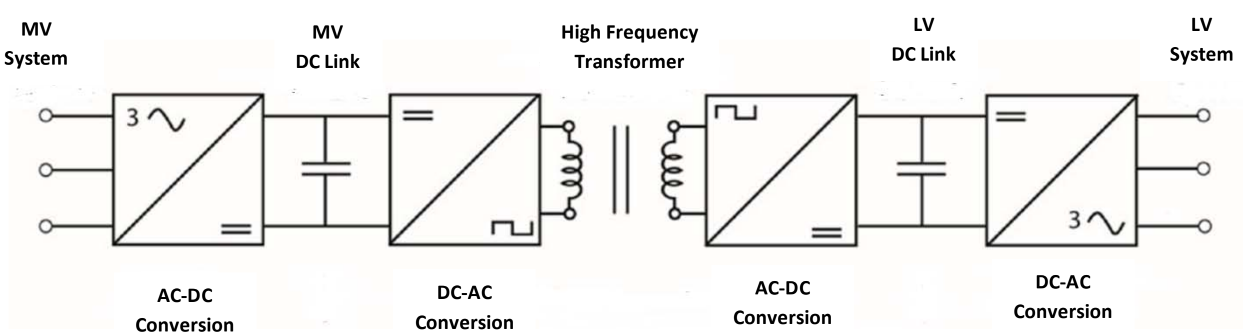
ii. *Technological Rivalry Continued*

However, the AC/DC technological rivalry did not stop. Two major roadblocks in DC grid deployment–transformers and circuit breakers–had to be, and were, resolved.

Transformers:

Low voltage in local DC grids (LVDC) was brought to higher levels. Today, DC-based renewable sources of electricity (such as wind, solar, tidal, wave) are collected at much higher voltages (e.g., $1500V_{DC}$ for utility-scale PV arrays) than in 1895, with the grid circuit losses considerably reduced.

Medium voltage for DC power distribution was achieved by Solid State Transformers (SST), often called DC transformers [52]. Solid State Transformers present an advanced combination of medium frequency (several kHz) AC transformer technology and AC/DC power conversion technology.



Credits: Scholarly Community Encyclopedia

Figure 2: DC Transformer Architecture

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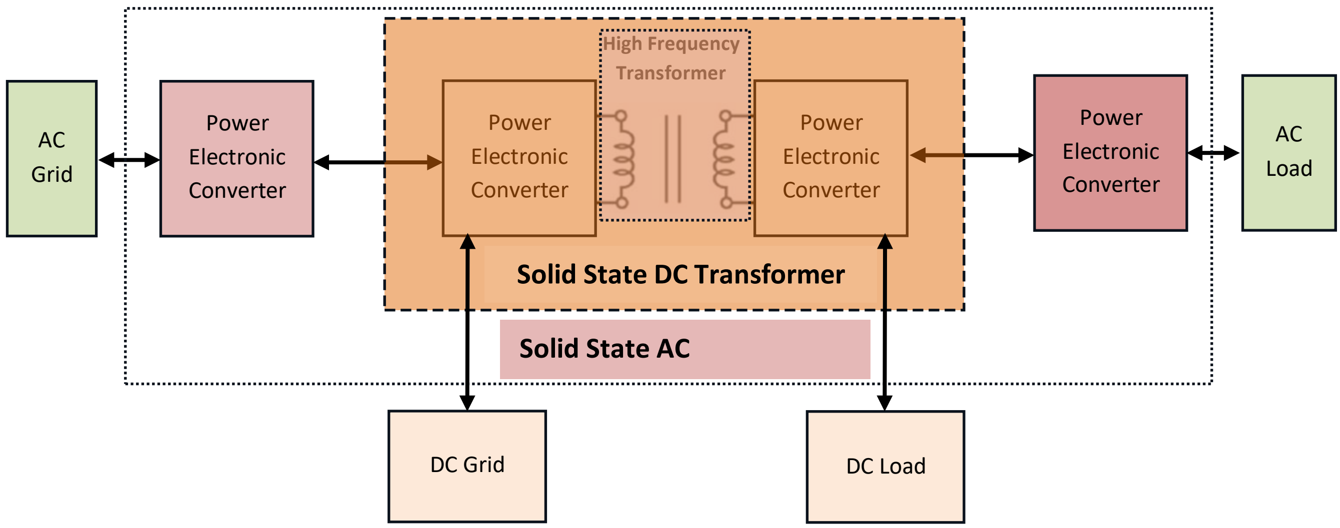


Figure 3: Solid State Transformer Applications

This allows for bringing Medium Voltage Direct Current (MVDC) grids from 1.5 kV_{DC} to up to 100 kV_{DC} voltage level [53].

DC Transformers for emerging MVDC grids due to increased frequency provide increased efficiency with significant reduced volume and weight [52,54].They optimize the links between renewable sources, loads and storage and reduce DC cabling losses.

Applications of transformers for MVDC have been also advanced for offshore floating and subsea transformer solutions [55,56].

Credits: U.S. Department of Energy

Figure 4: Example of Solid-State Transformer

High Voltage Direct Current (HVDC) lines commonly used for long-distance power transmission, operate in 100 kV to 800 kV voltage range. in 2019 a 1,100 kV link over a distance of 3,300 km with a power capacity of 12 GW was completed in China [57-59]; this demonstrates the level of intercontinental HVDC grid with large-scale wind and solar power plants interconnection [60].

Circuit Breakers

Another critical problem in DC grids was related to circuit breakers. In AC grid practice, a circuit breaker disconnects the circuit at a moment when the current becomes zero; this technique makes AC breakers simple and low-cost. The arc extinguishing technique in HVDC circuit breakers is much more complex, and the complexity of HVDC breakers equipment makes their costs higher [61].

The Power industry has been working on HVDC circuit breaker solutions since the mid-20th century [62]. While solutions in selected HVDC systems have been used and tested [63], only in 2012 ABB, one of the very few global leaders in HVDC deployment, announced that it solved "a 100-year-old electrical engineering puzzle…paving the way for a more efficient and reliable electricity supply system" [64].

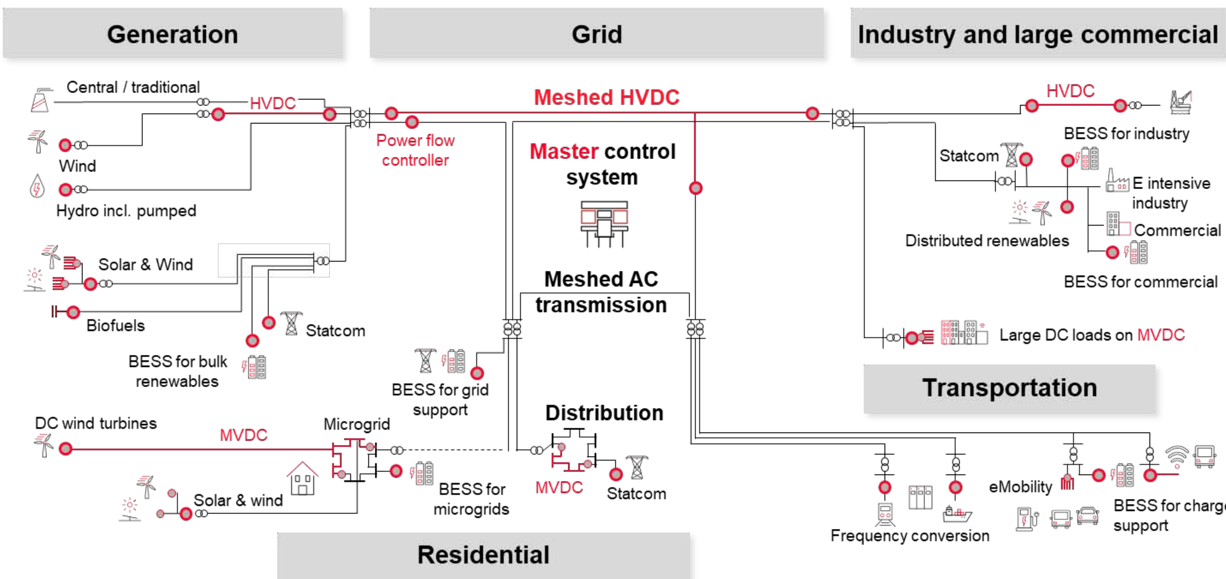
Credits: Progress on Meshed HVDC Offshore Transmission Networks, European Commission

Figure 5: 500 kV hybrid HVDC circuit breaker

As a result, by the end of 2010's the problems and "roadblocks" in dealing with DC grids -specifically highest quality of DC transformers and circuit breakers - have been resolved, and AC/DC competition has been brought to the next, very technologically advanced, level [48].

iii. *Merge on the Horizon*

As AC and DC systems started complementing each other [52], "rescuing" the Grid and moving from the current power grid to an emerging Future Grid, a big leap towards a "merge" of AC and DC grids appeared on the horizon. This merge expected DC grid solutions to match and shortly lead the development and deployment of Future Grid to meet the sustainability objectives within the timeframe required by a goal of 100% clean electricity by 2035.

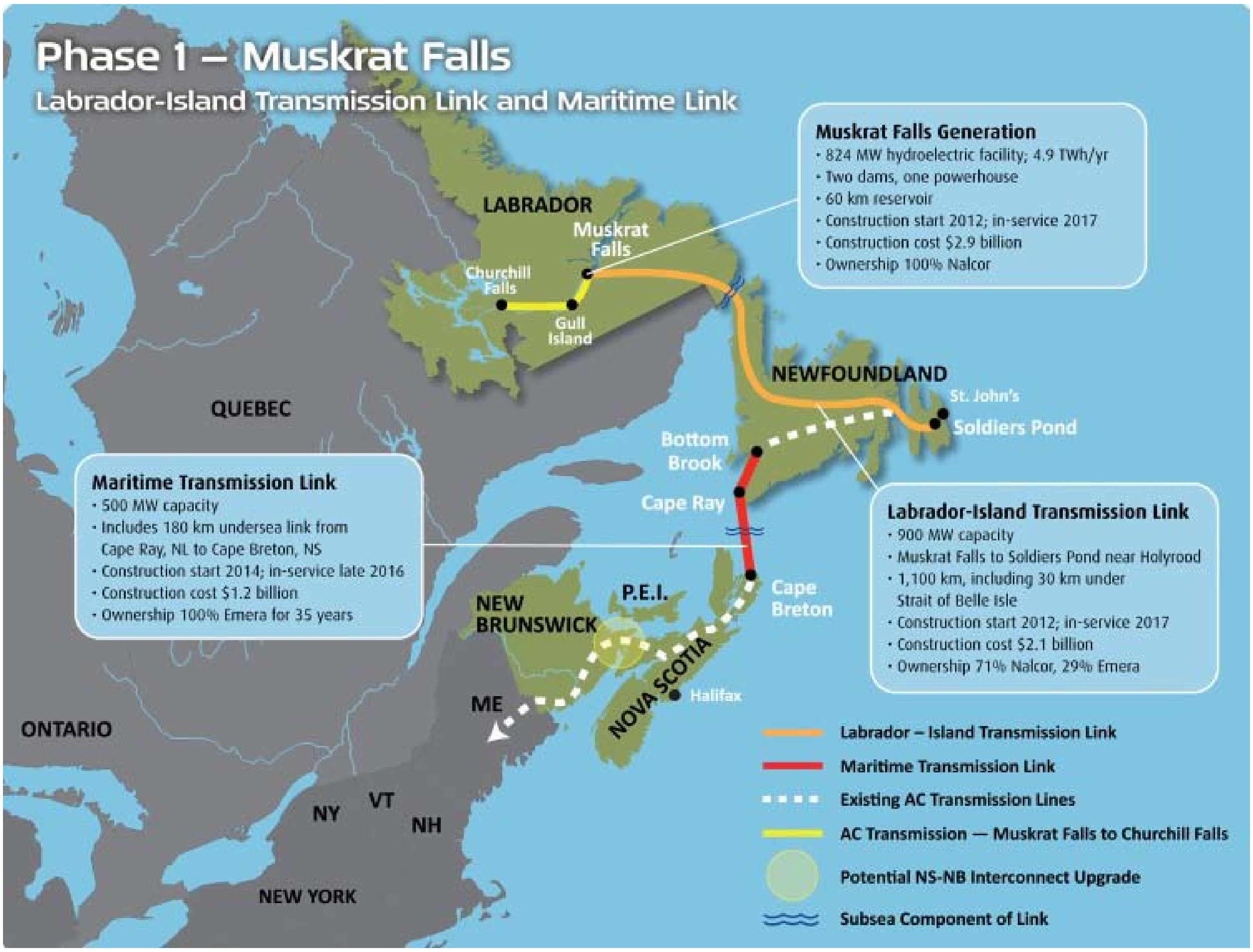


Credits: *Courtesy of Hitachi Energy*

Figure 6: AC and DC forming the Grids of the future [52]

The AC/DC 'merge leap' is driven by two industrial groups.

The first group includes the key multinational enterprises (MNEs) leading technology/product deployment of utility-scale converters (inverters and rectifiers) in modern HVDC solutions (such as Hitachi Energy's HVDC Light [65,66] or Siemens' HVDC Plus [67). These solutions are used for interconnecting renewable electricity sources (onshore and offshore) into the grids, utilizing back-to-back DC power stations to upgrade the resilience and coordinate independent parts of the grid [68], and bringing power to large consumption hubs from very remote clean electricity sources (such as Muskrat Falls, Newfoundland, Canada [69,90]).



Credits: Nova Scotia Energy and Mines

Figure 7: Maritime (subsea 500 MW) and Labrador-Island (900 MW) HVDC Transmission Links, Atlantic Canada

The second group is presented by electricity system operators accelerating transitions to advanced low emission power systems through manufacturing and deployment of grid forming converters (some of them known as Grid Forming Inverters) for Distributed Energy Resources (DER) interconnection with and operations in the grid [71,72]. This development is mostly focused on residential/community/commercial and smaller industrial clean electricity projects and plants.

This leap is also leveraged by utility-scale and residential/commercial/industrial scale battery storage solutions [73-75] as a key part of the Future Grid deployment. These battery storage solutions are already in the market.

To select the ways to accelerate the merge of AC and DC grid solutions to reach the Future Grid, let's look attentively at challenges and changes transforming Electricity Value Chain in Energy Transition.

c) *Transforming the Electricity Value Chain*

"When all five pillars of the TIR are interconnected, they create a new nervous system for the economy..."
Jeremy Rifkin[3]

i. *Value Chain Challenges*

As a continuous real-time match between electricity demand and supply, the electricity value chain in energy transition on the path to 100% clean electricity [76] is exposed to major challenges. Some important challenges, expected to be encountered to achieve the levels of clean electricity potentially reaching over 80% of electricity generation by 2030, include [77]:

- Deep penetration of variable energy sources like wind and solar in generation mix (where penetration is the amount of electricity generated from a particular source as a percentage of annual consumption);
- Interconnection/integration of commercial- or residential-level distributed and/or decentralized generation in distribution systems;

[3] Rifkin, J. (2011). The third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World. Macmillan.

- Dramatic changes in electricity consumption through electric vehicles' battery charging;
- Deployment/integration of advanced technologies to address the grid reliability and efficiency under changing conditions;
- Vast increase of data communications and related cybersecurity issues within the grid, and
- Meeting emerging power grid workforce requirements.

ii. *Future Grid Visions*

To address the electricity value chain challenges, visions of the Future Grid have been thoroughly envisioned by leading jurisdictions globally. As a key example, the U.S. presented its vision of the Future Grid as "seamless, cost-effective electricity system, from generation to end-use, capable of meeting all clean energy demands and capacity requirements" [78]:

Table 2: Vision of the Future Grid [78]

• Significant scale-up of clean energy (renewables, natural gas, nuclear, clean fossil)
• Universal access to consumer participation and choice (including distributed generation, demand-side management, electrification of transportation, and energy efficiency)
• Holistically designed solutions (including regional diversity, AC-DC transmission and distribution solutions, microgrids, energy storage, and centralized-decentralized control)
• Two-way flows of energy and information
• Reliability, security (cyber and physical), and resiliency

This vision supports the modernization of the U.S. electricity transmission and distribution system within a Smart Grid concept to maintain a reliable and secure electricity infrastructure meeting future demand growth [79]:

Table 3: U.S. Statement of Policy on Modernization of Electricity Grid [79]

1. Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
2. Dynamic optimization of grid operations and resources, with full cybersecurity.
3. Deployment and integration of distributed resources and generation, including renewable resources.
4. Development and incorporation of demand response, demand-side resources, and energy efficiency resources.
5. Deployment of `smart' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.
6. Integration of `smart' appliances and consumer devices.
7. Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.
8. Provision to consumers of timely information and control options.
9. Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.
10. Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

Energy transition, estimated to become a USD23-trillion market by 2030 [80], requires changes in the Electricity Value Chain addressing the inflexibility and prompt upgrades of grid infrastructure in a timely manner [81].

The highly centralized, one-directional Power Grid is currently being "reinvented", creating "an electrical power revolution"[82]. Most of energy demand will be met by electrical power; it is expected that electricity as a share of final global energy demand [83], will double from under 20% in 2022 to nearly 40% within the next 30 years.

The biggest barriers for power grids in energy transition are more socio-political than technical [82]. It is clearly understood that the grids of the future will integrate sustainability and circular economy solutions at every stage of the value chain [84].

Ensuring/enabling power grid flexibility to balance demand and supply in energy transition requires Dispatchable Emission-Free Resources [85]. It is expected to be addressed by major solutions such as grid coupling, generation management, demand-side management, and energy storage management [82].

iii. *"Soft Revolutions" in Value Chain*

With current challenges and visions behind Future Grid in the electricity value chain, we can see "soft revolutions" that have enabled energy transition. We will look at these "revolutions" bottom-up, beginning with consumption as a starting point in energy evolution, and move via distribution and transmission to electricity generation. We will also address "electricity storage" as a core part in each of the value chain links.

a. *Consumption: Changing Demand*

A. *Energy Management*

Historically, the Energy Management revolution started from energy security related to oil price events: Oil Shock with OPEC nations quadrupling price of oil in 1973 [85-89] and the Iranian revolution leading to second oil price rise in 1979.

As an immediate response, very initial Energy Management thoughts and practices moved to Energy Conservation, and further to Energy Efficiency [90].

In 2010-2020 Energy Efficiency was clearly understood internationally as a "fuel" [91-93] and an "energy resource" reducing the energy otherwise supplied by the electricity grid. Driven by carbon reduction requirements and implications of climate change, it was seen as" an important utility system resource, typically the lowest-cost system resource compared to supply-side investments" [94].

Based on the rapid advancement of cost-effective onsite distributed energy resources (DER) "energy efficiency" has become the "first fuel" – having "clean energy/renewable energy" as the "second fuel" in clients' energy mix, embedding it with digitalization and asset management through the Internet of Things™, and putting customers at the center [95]. Today sophisticated energy management approaches take advantage of technology, using real-time energy data analytics [96] and moving it to integrated, adept and robust predictive energy management practices [97] to increase clean energy productivity in the energy mix.

B. *Electric Vehicles and Fleets*

As oil prices and gasoline shortages in 1973 peaked, interest in lowering society's dependence on oil as vehicles' fuel started growing [98]. However, public interest in electric vehicles as an energy security/energy transition solution in the last quarter of the 20th century was lacking. Only at the beginning of the 21st century did interest in electric vehicles as a strong competitor to fossil fuel-based vehicles start increasing. This interest was supported by the growth of lithium-ion battery capacity. Together with continuous battery cost reduction, this spurred major auto-manufacturers to accelerate the development of EV solutions.

Over the last twenty years, the amount of EVs sold has dramatically expanded - from negligible in 2010, to approximately 1 million in 2016 and about 26 million electric cars by the end of 2022 in operation globally. Over 14% of global car sales in 2022 were electric. EV sales in 2022 increased by 60 percent compared to 2021 reaching a new record of 10.6 million. This rapid EV fleets growth meant that the society globally has already reached the tipping point in choosing electric mobility [99]. The International Energy Agency (IEA) predicts that the total fleet of EVs (excluding two/three-wheelers) will grow to about 240 million in 2030 accounting for over 10% of the road vehicle fleet and achieving an average annual growth rate of about 30%. Total EV sales are expected to reach over 20 million in 2025 and over 40 million in 2030, representing over 20% and 30% of all vehicle sales, respectively [100].

EV fleets represent the need in electricity delivery infrastructure to ensure electricity is always delivered where and when it is needed for EV battery charging. The global electric vehicle charging station market size was estimated at USD 26.9 billion in 2022 and it is projected to reach USD 344.6 billion by 2032 [101].

From the power grid perspective, EV infrastructure includes EV charging stations connected to the grid at-front-of-the-meter and behind-the-meter levels providing charging to all EV fleets (cars, trucks, buses, etc.) at public and private levels. This may also include solar PV and battery energy storage systems that may operate as a part of the charging stations.

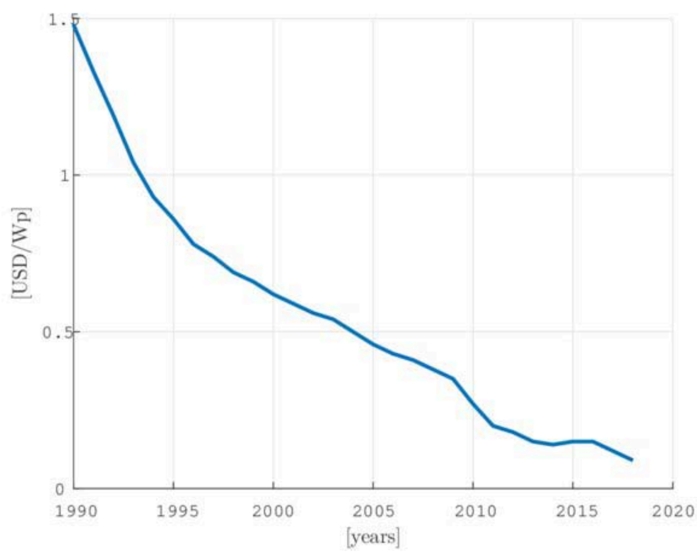
From the consumer angle, EV Infrastructure market segments may be presented based on Point of Charge addressing capital expenditure (CAPEX) risk levels (asset light or asset heavy) and charging speed (slow charging or rapid charging) [102, 103]; Mode of Charging defined by IEC 61851-1 (General Requirements), an international standard for electric vehicle conductive charging systems [104, 105], addressing AC-to-DC and/or DC-to-DC modes, and Type of Applications (public or private charging stations).

While the major mobile battery charging infrastructure markets are focused on EVs, there are other growing mobile charging infrastructure markets in transportation, such as battery storage based marine vehicles (ferries, boats, etc.).

b. *Transmission and distribution: Power Electronics*

Power electronics is a vital transformational technology for conversion and control of electric power [106, 107]. Today, power electronics performs power conversion and control and provides interfaces to all electricity solutions in the electricity chain in a broad spectrum of services necessary to the grid. Power converters enable the control the primary characteristics of electrical power such as voltage, current, frequency, and the basic form of AC or DC [108].

While historic use of mercury-arc valves in power electronics in the early 20th century limited its functionality, modern power electronic solutions based on solid-state semiconductor devices are much more functionally advanced. Power electronics strives today for compactness, efficiency and reliability, trying to reduce weight, volume, and life-cycle costs in a wide range of power applications [109].



Credits: 2019 Renewable and Sustainable Energy Reviews and Franco Penizzotto

Figure 8: PV system inverter price history

A breakthrough in power electronics in mid-20th century came with the invention of the MOSFET (metal–oxide–semiconductor field-effect transistor) by Bell Labs in 1959 [107]. Improvements in MOSFET technology made the power MOSFET available in the 1970s. In 1982, the insulated-gate bipolar transistor (IGBT) was introduced and became widely available in the 1990s. This "revolution" in power electronics, "quietly operating in the background – unseen and unheard" [106], brought to the market immediate applications for distributed generation, renewable energy systems, motor drives, electric vehicles, traction systems, marine systems. As an example, modular multilevel converters are replacing conventional voltage source inverters in HVDC applications and grid interconnection systems [110].

By 2030, it is expected that 80% of all electric power will flow through power electronics [111]. Its speed of reaction, flexibility of control, and scalability are key attributes ensuring resiliency of the future grid [106].

c. *Generation: Renewable Sources*

A. *Solar Photovoltaic Power*

Solar photovoltaics, a direct conversion of sunlight into electricity, started being implemented in telecommunications in late 1950's for space satellite applications [112]. However, successful PV revolution in power industry commenced through upgrading solar cell technologies' efficiency and cost in mid -1970-ies, bringing new markets for these technologies. In 1989, the first residential roof PV program was started in Germany, followed by a similar program in Japan. However, before 2000 PV was largely unknown by the general public [113, 114].

Changes on the market driven by Germany's Renewable Energy Sources Act triggered efficiencies in PV cells and modules. Best PV cell efficiencies of 13.9% in 1977 were brought to 25% in 1999 [115-117] and to 39.5% in multijunction cells [118] in 2021. Photovoltaic Module Efficiencies followed their cell efficiencies, reaching 25% for silicon modules [119]. Evolution of solar PV module cost demonstrated dramatic reductions: being 105.7 USD (2015) per Watt (W) in 1975, it reduced its cost in 2010 at 2.0 USD (2015) per W (50 times less!) and 0.2 USD (2015) per W in 2020 (10 times in the decade!) [120]. In the 2010-2020 decade there has been a 64%, 69%, and 82% reduction in the cost of residential, commercial-rooftop, and utility-scale PV systems, respectively with a significant portion of the cost declines attributed to an 85% cost decline in module pricing[121].

Starting from tens of megawatts of PV by 2000, the global PV base grew significantly reaching 1.2 TW of cumulative capacity in 2022, with 240 GW of new systems installed and commissioned, and nearly a dozen countries with penetration rates over 10% [122,123].

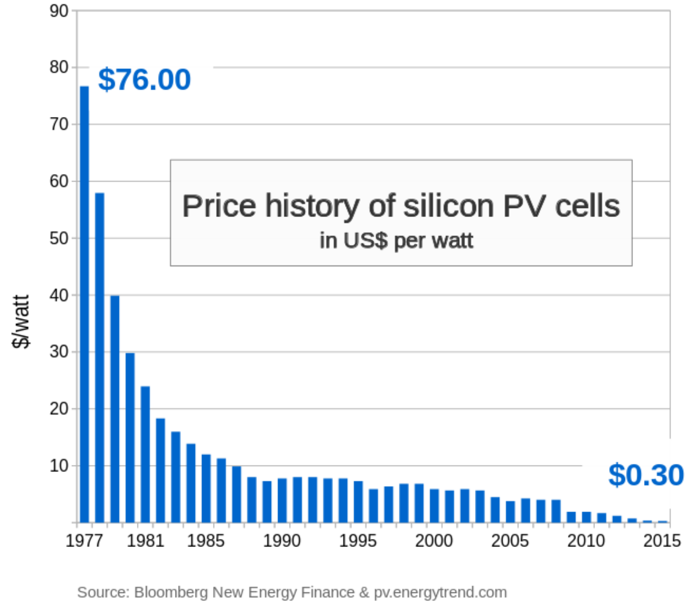


Figure 9: Silicon PV cells price history

The price of standard solar modules hit an all-time low of 16.5 US cents per watt in August 2023, expected to fall further by the end of the year to 14.5 cents per watt U.S.

Today, PV is a mainstream source of electricity at the core of the energy transition, addressing the challenges of climate change and presenting an immediate pathway to decarbonization [122].

B. *Utility-scale Wind Power*

While windmills were seen as an electricity source for many years, an important advancement took place in 1978 when the world's first multi-megawatt wind turbine with a lightweight three-blade upwind design was constructed in Denmark [125].

Rising concerns over energy security and climate change in the beginning of the 21st century led to expanding wind power industry due to abundance of wind resources and reducing utility-scale wind turbine costs [125].

Based on the northwest Europe's experience of the 20th century, deployment of land-based utility-scale wind turbines in the 21st century moved globally to off-shore (fixed bottom) and later – to floating off-shore wind solutions [126,127].

Becoming taller and bigger in design, wind turbines increased its capacities. As an example, the average capacity of newly installed U.S. wind turbines in 2021 was 3 megawatts (MW), up 9% since 2020 and 319% since 1998–1999 [128]. The average 2021 capacity (rating) for each of land-based, off-shore fixed bottom and off-shore floating turbines was 3 MW, 8 MW and 8 MW correspondingly, with capital expenditure rates indicated at 1,501 $/kW, 3,871 $/kW, and 5,577 $/kW, and Levelized Cost of Energy at 34 $/MWh, 78 $/MWh and 133 $/MWh correspondingly [129].

Financial and other incentives for wind energy development resulted in a large expansion of deployment in many countries. While in 1990, 16 countries generated a total of about 3.6 billion kWh of wind electricity, in 2021 at least 128 countries generated about 1,808 billion kWh of wind electricity. By 2021 wind energy produced 4872 terawatts-hour, 2.8% of the total primary energy production and 6.6% of the total electricity production [130]. In the U.S. only, the share of U.S. electricity generation from wind energy has grown from less than 1% in 1990 to about 10.2% in 2022 [124, 131].

d. *Storage along the Chain: Batteries*

Enabling power grids with battery energy storage systems across the entire electricity value chain is clearly seen as crucial for the power industry in energy transition [132,133]. The reason is simple – embedded in any part of the grid (in front-of-the-meter and/or behind-the-meter), battery storage is capable of continuously reducing/removing imbalances between electricity demand and supply within any time range required by the grid. [134]

Initial understanding of storing electrical energy in rechargeable batteries to address the needs of the grid came in very late 19th – the beginning of 20th century [135]. Since that time, many efforts were dedicated to battery storage chemistries and related applications in electricity consumption [135].

Today, the current market for grid-related battery storage globally is dominated by lithium-ion chemistries [136,137]. The Power Battery revolution led by lithium-ion batteries started with three important lithium batteries developments in the 1980s that allowed for building the first rechargeable lithium-ion battery prototype in 1985 and its commercialization by Sony in

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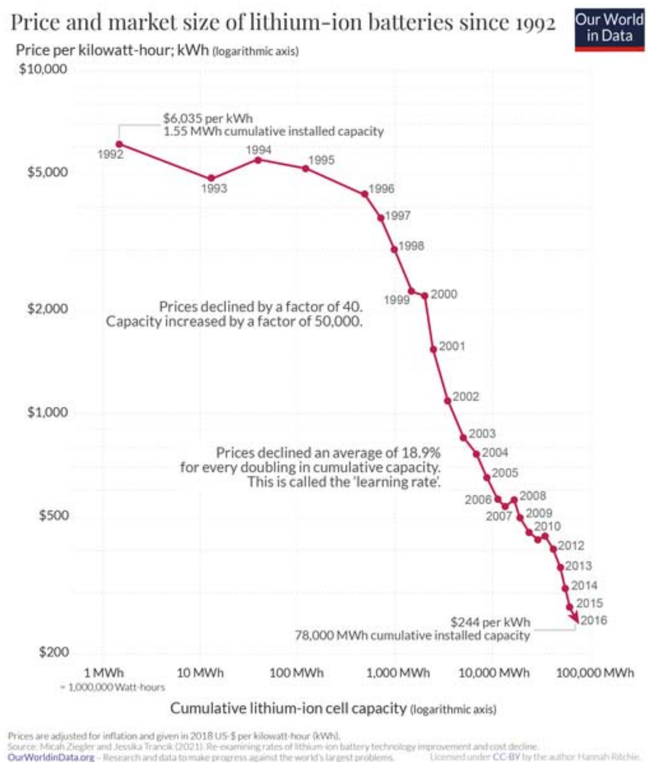
1991. Due to technological innovations and improved manufacturing capacity, the price of lithium-ion batteries in three decades declined by 97% [138] supporting their global use in leading markets such as telecom, power and automotive.



Credits: OurWorldInData.org

Figure 10: Lithium-ion batteries price history

As an example, in electrical vehicles manufacturing and sales, automotive lithium-ion (Li-ion) battery demand increased by about 65% to 550 GWh in 2022, from about 330 GWh in 2021[139]. According to US Department of Energy estimates, Electric Vehicle Battery Pack Costs in 2022 were nearly 90% lower than in 2008 [140].

In the power industry, developments in battery storage demonstrated commercially viable battery systems to store energy during peak production and release during peak demand. They also supported slower responding electricity resources during unexpected production falls [141].

Battery energy storage systems are critical for addressing high renewable energy sources penetration. They can support voltage and frequency regulation to maintain grid's stability and reliability, due to their high energy efficiency, quick response time, and long lifecycles. They have the ability to keep up with sudden changes in generation and consumption, and have low environmental impact [142,143]. They also enable energy storage systems modularization and flexible installation. Lithium-ion batteries in energy storage systems also exhibit relatively high energy density [144].

The two immediate applications of grid-connected battery storage systems are energy arbitrage (storing surplus electricity at low cost and using it when demand is high and prices increase) and ancillary services (such as frequency and voltage regulation, peak shifting and shaving) to keep the grid stable. Expected volume-weighted lithium-ion battery pack price forecast for 2023 is $152/kWh and is continuing to decline. In power grid applications, stationary energy storage installation is expected at 28GW/69GWh levels, and turnkey battery storage system costs for 4-hr duration systems - at $300/kWh [145]. Recorded at 1.57 TWh level globally in 2022, lithium-ion battery manufacturing capacity is expected to reach 3.97 TWh in 2025 and 6.79 TWh in 2030 [146]. The cost and performance projections for utility-scale lithium-ion battery systems, with a focus on 4-hour duration systems, show the high-, mid- and low-level storage costs of $245/kWh, $326/kWh, and $403/kWh in 2030 and $159/kWh, $226/kWh, and $348/kWh in 2050 [147]. It is expected that utility-scale battery storage systems will grow around 29 percent per year for the rest of this decade [133]. The utility-scale installations forecast for 2030 (450 GWh to 620 GWh range) presents a share of over 85% of the total market.

III. Expected Results and Outcomes

a) *Psychological Tools at Hand*

"…until we understand the individual states of mind as well as the multiple webs of culture, our attempts at designing and preserving a "sustainable planet" will be virtually impossible."

Don Beck[4]

As a result of "soft revolutions" in the Electricity Value Chain, consistent movement toward Future Grid Development became possible. The next step was to accumulate human mind forces to make the leap towards the Future Grid.

As in all macro-scale evolutionary developments, it required the coordination of governments, academia, private sector, and civil sector to move forward, and to rely on people in all these sectors in leading this critically important work.

To ensure that this coordination on multiple levels was in place and the work was moving at defined or accelerated pace, socio-psychological tools for dedicated groups across all the four sectors also needed be in place to achieve the Future Grid Development within the 2025-2035 timeframe.

If a global search is currently under way to select the most proven socio-psychological tools at hand to address the envisioned changes, attention

[4] Beck, D. (2014, September 24). *Sustainable Cultures, Sustainable Planet: A Values System Perspective on Constructive Dialogue and Cooperative Action*. Integral Leadership Review.

should be paid to Spiral Dynamics Integral (SDi) [26, 27, 148], a socio-psychological toolset supporting and leveraging macro-scale projects.

Highly instrumental and well-known in the efforts of resolving geopolitical challenges, Spiral Dynamics Integral's conceptual system in the 21st century was applied to civil society issues in general. It has been comprehensively field-tested in some of the most complex environments such as South Africa, and large-scale projects such as Palestine and the Netherlands. Dr. Don Beck (1937 – 2022), the coauthor of and major lead on SDi deployment, was engaged with major government agencies, banks, energy companies, and airlines as well as with international financial institutions such as the World Bank. Dr. Beck's commitment to SDi deployment, helping to reframe how we define human-related issues and understand the people involved in addressing these issues, brought its conceptual system over the globe. The Centers for Human Emergence built on the pillars of SDi with Dr. Beck's guidance were founded in many countries (e.g., in the Netherlands, Germany, the UK and the Middle East). Today these centers and related organizations contribute to the civil society leadership in Climate Change adaptation, low-carbon economy and energy security.

This Chapter summarizes the reasons for using Spiral Dynamics Integral's socio-psychological toolset as a very strong match for Energy Transition and the AC/DC merge in Future Grid Development for Total Electrification.

i. *Sustainable Culture Index*

To maintain and strengthen Total Electrification objectives, and practices of learning, sharing and making decisions in National, Economic, Political, Professional and Epistemic areas, driven by the key sustainable cultures: Energy Security, Climate Change Adaptation, and Low Carbon Economy, dimensions and components of a Sustainable Culture Index structure based on the approaches in [28,31] may be useful:

Table 1: Sustainable Culture Index

Dimension:	Component	Brief Definition
Positioning Change	Culture Shift	Shift of the culture's center of gravity as conditions of existence change (evolutionary dynamics).
	Vision	Compelling vision with a sense of transcendent purpose and superordinate goals to create common cause.
	Domains	Economic, political, social, environmental, spiritual and educational domains integrated.
	Bottom-line	Quadruple bottom-line: purpose, profit, people, and planet.
	Timeline	Past-present-future completion timeline (for every issue, every function, every level).
Connections	Psychological Health	Systemic health and well-being at individual and collective levels.
	Collective individuality	Sense of collective individuality (seen as a blend of individuality and collectivity ratios).
	Dependency	Dissemination of self-reliance and responsible decision-making (at every level, in every function, and on every issue).
	Tension Management	Dynamic tension in destructive or constructive conflict.
Dynamic Development	Cause Maintenance	Causes and symptoms of problems in the changes development (in a simultaneous, interdependent fashion) and their resolution.
	Capacity Rebuilding	Capacity to re-build self-reliance and responsible decision-making if/when the problems of existence create greater complexity than available solutions.
Living open systems	Sharing	The culture codes transmitted to the present generation.
	Transition	Preparation of the youth for different conditions in the near and far future.
	Transcending	The culture transcended with previous ways of being included.

ii. *Spiral Dynamics Integral*

Evolution of Power Grid as the key tool of Energy transition in the 21st century requires society to address this evolution at an advanced psychological level, using tested theories, skills and practices of human development used over the last sixty years. These internationally proven, cutting edge, theories, skills and practices, enable humankind to make successful large-scale steps in evolution and are presented by Spiral Dynamics Integral thinking, publications and experiences [26, 27, 148, 149].

The Spiral Dynamics theory of the evolutionary development of individuals, organizations, and societies is based on many years of research by developmental psychologist Clare W. Graves [150, 151]. Dr. Graves proposed to see the psychology of mature human beings and societies as "an unfolding, emergent, oscillating, spiralling process, marked by progressive subordination of older, lower-order behavior systems to newer, higher order systems as man's existential problems change".

The Spiral Dynamics theory was initially published by Don Beck and Christopher Cowan [26] and advanced later by collaboration of Don Beck and Ken Wilber in "A Theory of Everything: An Integral Vision for Business, Politics, Science, and Spirituality" [27].

iii. *Value Systems Approach*

According to Spiral Dynamics, the human mind adapts to more complex thinking when faced with similarly complex life experiences. From this angle, the Spiral Dynamics conception which leverages "a values system perspective on constructive dialogue and cooperative action" [28] presents a unique approach to major human developments such as the evolution of the Power Grid. Spiral Dynamics describes value systems as social stages of people, organisations and society as they move through their development.

a. *Tiers*

According to the Spiral Dynamics theory [26], two tiers of value systems are seen over human history. First-tier value systems describe the various worldviews, mental attitudes, and cultures from history until the present moment. Second-tier value systems describe more advanced, enlightened, evolved, or aware value systems.

THE LIVING STRATA IN OUR PSYCHO-CULTURAL ARCHEOLOGY				
Stage/ Wave	Color Code	Popular Name	Thinking	Cultural manifestations and personal displays
8	Turquoise	WholeView	Holistic	collective individualism; cosmic spirituality; earth changes
7	yellow	FlexFlow	Ecological	natural systems; self-principle; multiple realities; knowledge
6	Green	HumanBond	Consensus	egalitarian; feelings; authentic; sharing; caring; community
5	Orange	StriveDrive	Strategic	materialistic; consumerism; success; image; status; growth
4	Blue	TruthForce	Authority	meaning; discipline; traditions; morality; rules; lives for later
3	Red	PowerGods	Egocentric	gratification; glitz; conquest; action; impulsive; lives for now
2	Purple	KinSpirits	Animistic	rites; rituals; taboos; super- stitions; tribes; folk ways & lore
1	Beige	SurvivalSense	Instinctive	food; water; procreation; warmth; protection; stays alive

Credits: Don Beck 2014

Figure 11: Value Systems

Cultures are formed by the emergence of value systems defined as human responses to life conditions. As a complex adaptive intelligence, a value system "forms the glue that bonds a group together, defines who they are as a people, and reflects the place on the planet they inhabit" [28]. Any value system is a human undertaking: people requesting a change and people involved in defending this change and making it a success.

b. *Composite Value Systems*

According to Don Beck, "social stages within cultures [have] the capacity to lay on new levels of complexity (new value systems) when conditions warrant…Each emerging social stage or cultural wave contains a more expansive horizon, a more complex organizing principle, with newly calibrated priorities, mindsets, and specific bottom-lines…All of the previously acquired social stages remain in the composite value system to determine the unique texture of a given culture, country, or society" [28].

c. *Integral Theory*

Ken Wilber's Integral Theory in Spiral Dynamics Integral concept presents a framework for understanding the relationship between the individual and the collective, and between internal and external views. As a four-quadrant map (intentional, behavioral, cultural and social), that may change in time, the Integral Theory reflects the impact of people involved in any value system related changes. This allows for balancing Diversity generators which promote individual initiatives and Conformity regulators that reward collective actions, as well as Internal (“about me or us”) and External (“about them”) thoughts. [149]

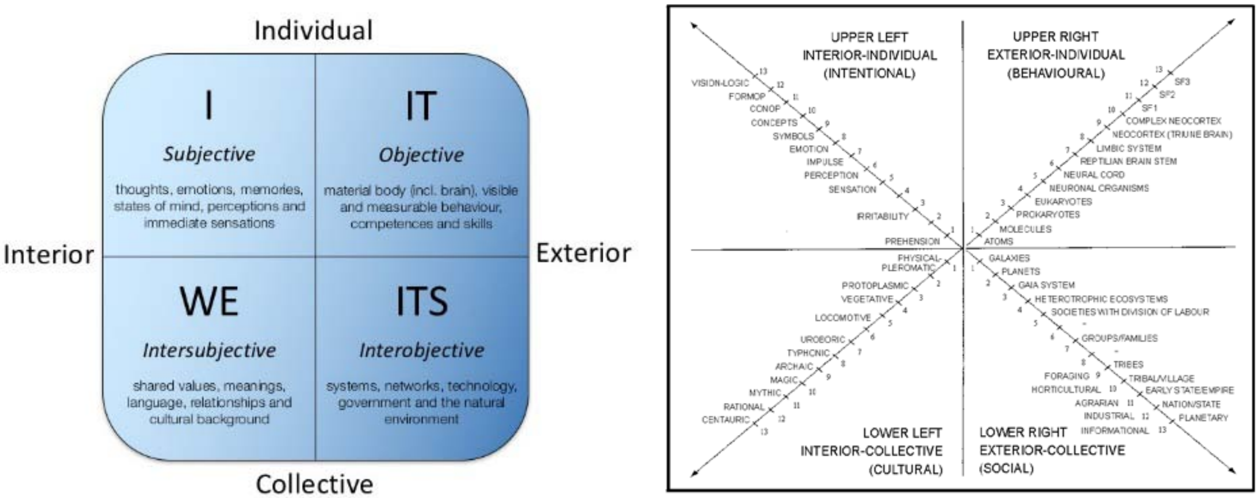


Figure 12: An Integral Theory of Consciousness (Ken Wilber, 1997)

iv. *Value System and Subsystems*

As an evolutionary development, the Total Electrification culture in the 21st centurybrings out value systems that “present ecological thinking, and rely on natural systems, self-principle, multiple realties and knowledge as cultural manifestations” [28]. These value systems (systemic, ecological, flexible, conceptual) emerged around 1950 and matured by early 21st century. In Spiral Dynamics theory these value systems are often called by Yellow colour and/or by Flex Flow name (see Figure 11).

In the Total Electrification culture with current experience in all areas of life, Energy Transition based on clean energy solutions is seen as a value system providing response to life conditions on the planet, current and expected in the future.

The Future Grid approach to promptly and robustly upgrading electricity grids and achieving the grid performance objectives is a critical toolset for Energy Transition. It ensures this value system empowering the Electricity Value Chain will be very successful in relatively short period of time (within 2025-2035 timeframe). As such, the Future Grid presents itself as a value subsystem within the Energy Transition value system.

v. *Future Grid Value System Features*

The changes expected through or experienced as a result of the Future Grid Development may be clearly seen through FlexFlow (“Yellow”) *value system features*:

- SYSTEMIC:
  - o Market Decentralization:
    - ▪ *Binding micromarkets to microgrids* at any level of decentralization/distribution – from retail micromarkets to wholesale macromarkets.
      - Micromarkets are a means to balance electricity supply and demand within a microgrid. Microgrids as smaller scale, “local” parts of larger power grids ensure reliability, cost and carbon footprint reduction, and DER diversification, and provide stability to larger grids [152]. Binding micromarkets to microgrids they serve enhances balance of electricity supply and demand. Micromarkets operate with multiple market participants within the microgrid [153].
      - Microgrids are market participants in larger microgrid or grid markets they are a part of where they operate as buyers (“virtual users”) or sellers (“virtual plants”).
    - ▪ *Transactive Energy*: micromarket participants' electricity procurementnegotiations based on real-time smart load operations[154-156]:
      - Users' smart loads operate based on intra-day electricity price forecasting to meet electricity needs while reducing overall electricity demand and cost.
      - The micromarket coordinates overall demand with a larger market.
      - All parties negotiate energy procurement and consumption levels, cost, timing and delivery in a dynamic pricing scheme.

- o Control Decentralization:
  - ▪ *Control Resolution*: move from "centralized only" to "fully decentralized" microgrid control architecture, self-organization of any microgrids (no central control).
  - ▪ *Real-time micromarket control*: *Intra*-day and intra-hour scheduling of Distributed Energy resources in microgrids, control solutions for micromarket management [157].
  - ▪ *Microgrid reliability and security optimization*: self-contained autonomous system enabling self-control, protection, and management while meeting customers' demands for power quality and supply security [158, 159].
  - ▪ *Electricity User Control*: rapid response, energy efficiency, user satisfaction [160].
- ECOLOGICAL:
  - o Move from fossil fuel sources of energy to cleaner sources of electricity,
  - o Use of natural gas and nuclear as the electricity bridges to 100% clean electricity practice,
  - o Consistent growth of renewable sources at utility-scale, community-scale and end-user scale levels
  - o Continuous growth of clean electricity resources beyond existing solutions on the market via new electricity generation (e.g., floating offshore wind, tidal, concentrating solar power, etc.) and electricity storage (electrochemical (e.g., hydrogen fuel cells), thermochemical (e.g., high temperature thermochemical), etc.) commercialization.
- FLEXIBLE:
  - o Power Grid flexibility is completely based on power electronics used for electricity transmission and distribution.
  - o For transmission at high-voltage (HV) and medium-voltage (MV) grid levels, high power voltage source converter (VSC) technology and products are used by Flexible Alternating Current Transmission System (FACTS) and High Voltage Direct Current (HVDC) solutions. These solutions use Modular Multilevel Converter (MMC) and Solid State Transformer (SST) technologies and techniques.
  - ▪ FACTS solutions are used in AC grid transmission to stabilize the grid; they include power electronics equipment and service for voltage, frequency and load flow control [161-166] enabling:
    - Blackout prevention
    - Grid forming capability.
    - Inertial response to the transmission system from virtual and natural synchronous machines
  - ▪ HVDC solutions are used in DC grid transmission; they include power electronics equipment and service for [165]:
    - Integration of remote utility-scale renewable energy generation (e.g., PV and offshore wind farms) and consumption (e.g., mining plants).
    - Interconnection of regional medium-voltage grids – interties (back-to-back stations) can be used to create an asynchronous interconnection between two AC networks.
    - Interconnection of islands and other autonomous systems.
    - Backup solution for existing local supply.
  - o For distribution at low-voltage (LV) level the following is used:
  - ▪ Grid Forming Converters for DER Management [71,72]
    - Operations in an electrical island ("forming" the grid voltage and frequency) or synchronization to an external grid,
    - Immediate response to changes in the external system
    - Stability during challenging network conditions
  - ▪ DC Microgrids [167]
    - Operations in an electrical island,
    - High utilization of on-site power generation,
    - Optimization of heating, ventilation and air conditioning,
    - High electric vehicle charging capacity,
    - High reliability and resiliency during grid outages,
    - Lower capital investment and grid interconnection costs, higher operational savings through increased efficiency.
- CONCEPTUAL:
  - o Grid Decentralization:
  - ▪ Bringing electricity sources closer to electricity uses,
  - ▪ Microgrid as the core unit of the grid,
  - ▪ Micromarket decision-making in real time.
  - o Grid Digitalization:
  - ▪ Convergence into Cyber-physical-social systems [168]
  - ▪ System-of-systems architecture
  - ▪ Cutting-edge technologies (e.g., Industrial IoT, artificial intelligence, blockchain, cloud storage, etc.)
  - ▪ Virtualization of operations [169]
  - ▪ Enhanced utilization of the grid infrastructure
  - o Grid Decarbonization [170,171]:
  - ▪ Generation and Transmission: reducing carbon footprint by operating carbon-free baseload generation, retiring carbon-intensive generation, adding new renewables and storage, facilitating

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grid modernization including HVDC transmission lines,

- Distribution: reducing carbon footprint by reducing line losses through grid infrastructure upgrade and demand flexibility capabilities, pursuing customer-centric decarbonization opportunities focused on energy efficiency, customer-sited distributed generation and storage, and electrified transport [172],
- Consumption: low-carbon supply to all commercial and industrial customers.

o Environmental, social, and corporate governance (ESG) in the grid

- Grid Sustainability,
- Biodiversity: net-positive biodiversity impact,
- Circular Economy: reusing, recycling, avoiding waste.

o Climate Change Adaptation:

- Proactive risk management as a business imperative [173],
- Impacts on grid infrastructure,
- Adaptation paths[174]:
  - Hardening the Grid
  - Decentralizing Electricity Sources
  - Strengthening resilience through Microgrids
  - Growing Energy Storage
- Adaptation management planning.

b) *Conditions for Change*

"Commonities = Commons + Communities"
Søren Hermansen[5]

Society's ability to understand and successfully make the changes towards the Future Grid, based on Spiral Dynamics Integral model, are based on six conditions for change [176]:

(1) Search for subsistence solutions and problems,
(2) Dissonance in the current value system,
(3) Potential of collective and individual thinking,
(4) Understanding of barriers to change,
(5) Probable causes and viable alternatives,
(6) Consolidation and support during the transition.

An approach to these conditions for change in Future Grid for Energy Transition is described below in more detail for North America and Europe.

i. *Subsistence Solutions*

In general terms, at any social stage of development the target level of subsistence is achieved by earlier or current generations. After many efforts, over time, the problems preventing desired activities are resolved/removed, and the target results achieved.

From electrification and power grid history we know that the electrification effort started at the end of 19th century, and that AC-based grid practices and operations were established in 1930's. From that period and until 2010's, the existing AC power grid had been covering most of the electricity value chain needs, and technical problems in the grid maintenance and balanced operations had been resolved. One important feature of the AC power grid was infrastructure aging which, through close to 100 years of AC grid operations, brought growing capital investment requirements. It also made clear deeper understanding of possible limitations of AC grid if dramatic changes in electricity supply and/or demand occur.

ii. *Dissonance*

To recognize any reasons leading to dissonance in the current value system, we have to be aware of and accept a clear and growing gap between the already changing conditions and the current ways we have been dealing with these changes. We need to understand that something is wrong with the current value system and that solutions we are trying to apply to emerging problems could be destructive and lead to "dead ends".

Applying this approach to the Future Grid value system, we see that a clean electricity gap in the grid is growing with the growth of renewable sources. The current approaches to manage the stability of the grid are limited to increasing renewable electricity curtailment (this means – keeping clean electricity at low transmission, distribution and consumption levels) and investment in additional transmission equipment, expensive and time-consuming to install [177].

Inevitable investment in growth and deployment of renewable resources in energy transition, on one hand, and their curtailment in daily practices on the other hand, has already created a strong turbulence, indicating that something is wrong with the grid.

The limits imposed on renewable energy to be installed/interconnected while society is strongly requiring their rapid growth are demonstrating that solutions applied to the grid of the 20th century have been failing when confronted with the experience and thinking of the 2020's.

iii. *The Potential of Thinking*

Collective and Individual thinking has to ensure that the way to change is open:

- Integrated history and conditions for openness are present,
- Strong forces creating turbulence are understood,
- Ability of organization(s)/people to participate in the intended direction is determined/Potential for functioning at a higher level of complexity is available,
- Decision to move is made.

[5] Hermansen, S. & Nørretranders, T. (2013). *Commonities = Commons + Communities*. Samso Energy Academy. ISBN 9788792274007.

Defining this condition in terms of the Future Grid, we see the following.

- Integrated history and conditions for openness in terms of Future Grid are clearly present – see Chapters 1 and 2 of this essay. Integrated history of power grid is well understood by electricity/power industry, and all the four major sectors in the society: government, academic, private industry and civil sector are open for immediate change related to energy transition including clean electricity from solar and wind, power conversion, and electricity storage.
- The three strong cultures creating turbulence for Energy Transition and the Future Grid - energy security, low carbon life cycle, and climate change adaptation - are clearly seen in and felt by society.
- Ability of organization(s)/people in each of the four society sectors to participate in the intended direction to reach the expected Future Grid level within 2025-2035 time frame is determined. Good examples of leadership commitments in the U.S. are presented by organizations at federal (e.g., [78]) and state (e.g., [85,178]) levels, by academia (e.g., [77]), and by all multinational enterprises involved in power industry in the country. Highly growing residential solar and battery markets contribute to Energy Transition, and human resources related to these sectors (e.g., system installation, electricians involved) match this growth.
- Human potential for functioning at a higher level of complexity in the Future Grid leap is available, however understanding of DC grids and AC/DC merge, specifically in relation to utilities and contractors' services and practices, has not been publicly discussed and promoted.
- Decision to move to Future Grid has been made in all the government, academia and private sectors (see the USDOE Future Grid publication [78] as an example).
- The potential of collective and individual thinking in these sectors is available, people are skilled and ready so the way to change is open.

iv. *Barriers to Change*

Speaking about the Future Grid development we should look at two levels of barriers to change: technical and organizational. We also have to include the change completion timeline, which in the case of Future Grid is rather prompt and has to be deployed in an efficient and timely manner.

In terms of technical barriers, the starting point for change deployment is well defined in Future Grid vision and planning documents, specifically by governmental departments of energy/electricity, system operators and regulatory organizations, and the industry. These documents define the next steps in moving to Future Grid. Based on this documentation, the barriers for moving to the Future Grid can make changes difficult, but not impossible.

Technically and technologically, the AC/DC merge can be successfully achieved in a very timely manner.

However, the AC/DC merge is still in very early phase administratively. A critical first step for its deployment - close national and international coordination - is still in progress. An important example of this step for acceleration of deployment of new products, such as MVDC or Grid Forming Converters, is the implementation of harmonized grid codes - technical specifications defining the parameters and conditions for access to the electric system that an asset connected to a grid has to meet to ensure safe, secure and economic operations of the system, and related standards development & technology adoption [177, 179, 180]. The administrative barriers for change should be recognized and clearly identified. This is most critical for low-voltage (LV) and medium voltage (MV) grid forming converters and related LVDC/MVDC grids in terms of AC/DC grid merge.

The complete representation of the electricity value chain participants has to be involved in each step of development with their internal and external positions aligned.

The leading groups coordinating development activities/operations in the Future Grid development should be approved and followed by the development participants.

These leading groups will continuously provide information about the costs of "not moving forward" as well as identify possible "dead ends" in the development and methodologies needed to resolve the problems/ issues and/or finding the constructive ways forward.

v. *Problems Causes and Alternatives*

It is expected that the Future Grid development curve may inadvertently step into possible "dead ends" because of mistakes being made. It is critical to see the results of these mistakes in advance, and here Future Grid Digital Twin approaches [181, 182] will help everyone stay on track and return to the successful development curve. Advancements in the Industrial Internet of Things (IIoT) techniques and smart measurement solutions already in progress (such as [183]) will leverage this development process. Additions/adjustments in Grid Codes covering the changes in Electricity Value Chain will reflect the response of the society at large and is expected the mistakes/problems will be fixed at very early stages.

Continuing advancements in professional expertise and experience and standardization of power grid through globally leading associations such as the Institute of Electrical and Electronics Engineers (IEEE), and the International Council on Large Electric Systems (CIGRE) has been and will continue to leverage the

AC/DC merge development. This will allow for better defining and achieving the Future Grid development curve milestones and consideration of several alternatives to keep at hand should a problem be identified at every grid development milestone.

vi. *Consolidation and Support during Transition*

To ensure the AC/DC merge is successful and Future Grid milestones and achievements are in place, a supportive culture for the Future Grid deployment is needed.

One of the objectives of this supportive culture is to search for "innovative ways and skillful means"[28] to convey information and knowledge about AC/DC merge across the society and leverage the constant interplay of personal, organizational, and societal developments [149].

A key component of this culture is the Coalescing Authority, Power, and Influence (CAPI) approach [184, 185] to AC/DC merge. *Authority* here refers to those who represent the system; *Power* indicates those who can support or sabotage; and *Influence* involves those with expert views or insights.

An important example of creating this supportive culture in AC/DC merge is presented by the Global Power System Transformation (G-PST) Consortium founded by the six leading electricity system operators in energy transition: National Grid ESO (Great Britain), Ireland's EirGrid, Denmark's Energinet, The Australian Energy Market Operator (AEMO), California's Independent System Operator (CAISO), and The Electric Reliability Council of Texas (ERCOT).

The G-PST Consortium acts as a force multiplier to achieve "a century's worth of energy transition progress this decade" [186]. It "...convenes expertise across a network of system operators, manufacturers, utilities, standards bodies, and research institutions" bringing together "key actors to foment a rapid clean energy transition at unprecedented scope and scale" and provide "coordinated and holistic "end-to-end" support and knowledge infusion to power system operators" globally [187].

The G-PST Consortium operates across five key areas ("pillars") and implementation councils.

Pillar 1 – "System Operator Research & Peer Learning" - is led by The Energy Systems Integration Group (ESIG), the leading source of global expertise for energy systems integration and operations and the only non-profit educational association [188].

The Grid Forming (GFM) Converters Implementation Council, being a key driver tor AC/DC merge, is focused on GFM field test & demonstrations, and cross-cutting standards development & technology adoption [180]. Today ESIG acts as a global lead in Grid Codes alignment for Grid Forming Converters.

The efforts presented by ESIG and its collaborators contribute to developing a constructive dialogue focused on the nature of problems and their unique solutions in AC/DC merge, and cooperative action to "mobilize quickly and skillfully all of the resources necessary" [28] and meet the AC/DC merge objectives in energy transition and energy security to the global target level.

IV. Conclusion

The total electrification of our society is being forced by the most critical sustainable cultures in the world: Energy Security, Climate Change Adaptation and Low Carbon Economy led in early 21st century by Energy Transition. "Soft revolutions" in clean electricity generation and consumption, battery storage, and power electronics technologically enabled this transition.

Today, the key driver of Energy Transition empowering the electricity value chain is the rapid transformation of existing electricity (power) grid into the Future Grid. This global evolutionary development with high-pace transformational efforts based on a combination of techno-economical and psycho-social understanding of human systems is accelerated in the current decade.

A strong leap is being done towards the Future Grid architecture and deployment necessary to have energy transition succeed, and the core of this leap is an AC/DC grids merge. The key insights characterizing the AC/DC grids merge are as follows:

- *Dynamic Spiral nature of power grids*: What was seen and experienced in DC and AC grids in 1880's and 1890's kept human mind continuously focused on finding the best of AC and DC, and successfully fixing the problems, thus bringing AC/DC grids merge concept in 2020's to a qualitatively and quantitatively new level.

  This concept has been strongly driven by dramatic changes in electricity generation (e.g., renewables), transmission and distribution (e.g., solid state transformers) and consumption (e.g., electric vehicles) in the total electrification process.
- *Commitment to the AC/DC grids merge in society*: There is a growing public understanding that the AC/DC grids merge in the Future Grid being currently developed is becoming a must. This understanding is based on expected increase in electrification increasing Energy Security and related Quality of Life. It's also based on achievements in Climate Change Adaptation such as hardening the grid, decentralizing electricity sources, strengthening resilience through microgrids and growing energy storage. Finally, this understanding is based on the expectation that AC/DC grid merge completely based on power electronics will leverage the strength of the low carbon economy.

  The significance of the Future Grid with the AC/DC grids merge as its core, and related commitments of society are also very important for the broader societal goals addressing low carbon economy and sustainability, such as many of the United Nations' Sustainable Development Goals.

- *Grids Merge Resolution*: AC/DC grids merging is expected at all transmission and distribution levels. To ensure this, DC equipment will be manufactured and microgrids deployed at low voltage direct current (LVDC) and medium voltage direct current (MVDC) grid levels. It also means that Grid Forming converters will be manufactured and deployed to connect to and support AC grids.

  Immediate steps in paving the way for the Future Grid, encouraging the market to request necessary equipment and the industry to promptly invest in its manufacturing, are being currently fast tracked to harmonize the requirements to grid codes for DC grids and Grid Forming converters.
- *Constructive Dialogue and Cooperative Action*: Participation and close collaboration of all the government, academic, private and civil sectors of society in decision-making and deployment of AC/DC grid merge is critical from the very beginning of this process.

  Today's ability to meet the Future Grid target is currently demonstrated by technical, business and research expertise [186, 188]; it shows a detailed level of conditions to make the changes required for successful deployment. A powerful starting point already exists for developing a constructive dialogue focused on the nature of problems and their unique solutions in AC/DC merge. This starting point also allows for a cooperative action to "mobilize quickly and skillfully all of the resources necessary" [28] and promptly engage the civil sector that has not yet been fully involved, to leverage personal, organizational, and societal developments. This will allow for meeting the AC/DC merge objectives for the Future Grid, and for bringing energy transition and energy security to a higher global level.

  An important aim of this manuscript is to bring attention of possible readers to the Future Grid development and to encourage them to contribute to a timely and successful AC/DC grid merge at any personal or/and professional level. It is anticipated that individuals, organizations, and policymakers can contribute to the success of the Future Grid via existing or new Future Grid Forums and Networks. The Author warmly hopes that many members of the civil sector representing communities or individual groups at local level will participate in this important work.
- *Socio-psychological tools at hand*: Using known and available methodologies and practices to address macro-scale problems and solutions of the AC/DC grid merge.

  To ensure that this coordination on multiple levels for government, academic, private and civil sectors is in place, that the planned work is moving at accelerated pace, and the Future Grid milestones are met on time, socio-psychological tools for dedicated groups across all the four sectors should be used to achieve Future Grid Development within the timeframe required by a goal of 100% clean electricity by 2035.

  These socio-psychological tools can leverage efforts in managing and advancing multi-stakeholder collaboration, help establishing and maintaining sustainable ties, and ensure all stakeholder forces are joined to succeed. As a positive example, Spiral Dynamics Integral methodology and practice is recommended as a socio-psychological toolset for all the four society sectors involved supporting and leveraging a global macro-scale Future Grid Development. This practice is based on multi-stakeholder collaboration; it starts from a deep understanding the backgrounds of the stakeholders' historical thinking and emerging needs to develop strategies, clarify and strengthen the unique role of each stakeholder, and guide various stakeholders towards a common, overarching goal [189].

Overall, the implications of successful Future Grid Development based on the AC/DC grids merge demonstrate its very positive impact on high-scale clean energy adoption and energy transition to achieve the total electrification targets. These implications also show a strong positive impact made by the AC/DC grids merge on environmental sustainability, and economic growth within the low carbon economy.

Acknowledgments and Conflicts of Interest

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Conflicts of Interest

The author declares no conflict of interest.

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One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation)
by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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