Thermal Impact Analysis of Circulating Current in High Power Modular Online Uninterruptible Power Supplies Application

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PCmRC: The conceptual model of future consumer-grid.

Topic 6.c. Microgrids – (UI) – Lecture Presentation

Abstract—*In this paper, we have proposed distinctive grid-model for integration of renewable-sources, storage and AC-maingrid inside consumer-grid known as Power-controlling-monitoring-routing-center. The main objectives are to maximize the exploitation of renewable-sources, to decreases reliance on fossil-fuel, to reduce the power-conversion losses and full management of end-user demand in all possible forms.*

I. INTRODUCTION

The concept of DC microgrids arises and has become one of the hottest topics of renewable energy research. This field has been regarded as one of the 10 most emerging technologies by "Massachusetts Institute of Technology (MIT)" review in 2012 [26]. The modern concept of microgrid based power distribution is showed promising on the bases of following advantages. i) The transmission losses can be reduced as compared to AC distribution up to 8-10% [25]. ii) Local grid can be constantly monitored, which increases the power quality and reliability of entire grid. iii) Integration of variety of renewable sources at any stage in power generation plant becomes possible, with low carbon footprint. iv) Both types of short-term and long-term storages can be incorporated within grid and play important role in control and operation of a microgrid. v) It significantly contributes in reducing the effect of the natural disasters by rapid restoration capabilities. Moreover, a classical layout of the DC microgrid is also simple and consists of few components such as Grid-interface, renewable generators, demand-side management, and energy storage. Following are the list of advantages of DC power grid over a convectional AC power grid.

- Mostly, renewable sources generate DC power except wind turbine. Typically output of wind generator is converted into DC power before transmission.
- Nowadays, mostly appliances (such as LED lights, smart-phones, and computers) operate on DC power. Therefore, DC powered microgrid will reduce the power conversion losses by eliminating power-inverter stage in between DC source and DC load.
- There is no need to consider frequency synchronization and reactive power issues, between different DC power sources. Therefore, it leads the high power quality within reasonable cost.
- Energy storage can be directly coupled with the DC distribution bus without additional power converter. Therefore, surplus stored energy can be utilized without significant loss.
- DC-DC converters are more efficient and cost effective then same wattage of inverter (AC-DC). Therefore, whole system cost and energy loss can be reduced.
- Few components used in DC microgrid, hence mean time between failure (MTBF) of DC grids is usually high [34].

In several other applications have been reported in which DC microgrids has been successfully implemented such as Naval ships, aircrafts [12, 5], commercial data-centres [29, 7, 38], residential buildings [33], and communities [10, 28, 24, 34], DC microgrid control [8, 32, 11, 3], DC distribution [16, 22, 6, 28]. However, DC microgrids associated issues and challenges regarding low-cost and reliable DC protections [4, 5, 30, 21, 20], intermittent distributed energy storage [38, 39], grid-connected operations [13], autonomous operations, communications, islanding operations [18, 29, 32], inverters topologies for power transfer [13].

In order to solve above mentioned challenges, DCT (DC Transformer) based consumer grid model presented in this paper known as PCmRC (Power Controlling, Monitoring and Routing Centre) as shown in the Figure 1. The DCT is used to interface the high-voltage and low-voltage DC buses. The topology used in the DCT module supports bidirectional and multilevel DC to DC conversion, which can be used to interface the high DC voltage bus with low-voltage battery storage without any additional power converter. In this way, the overall power converters count and energy loss can be reduced within grid. In PCmRC, DCT module can regulate the voltage on both high and low side with embedded over voltage and short-circuit current protection on each terminal. Therefore, there is no need to install additional expensive DC protection system, which helps to lower down the overall grid operational cost, which is shown in the Figure 2(b). The battery storage can be coupled directly on the low-voltage bus, which prevents voltage-dip or glitches on driving heavy loads. The most important feature of DCT enabled consumer grid is the independent and similar control with and without AC grid connection. It means there is no significant difference in control and operation of overall PCmRC consumer-grid in grid-connected, islanding and off-grid modes. In literature, several research studies have been done and researchers proposed different SST (solid-state transformer) enabled DC microgrid architectures. In [17], authors proposed bipolar LVDC distribution model. The whole grid operation is controlled by supervisory computer; therefore the grid reliability is depending upon single-point communication link. Recently, some proposed SST based DC microgrids are gaining popularity such as [36, 11, 34, 35, 13, 40]. Most of the proposed models are based on intelligent AC-DC Solid-state transformer (SST) for grid-connected operation and the output of SST module consist of high-voltage DC only. Therefore, additional DC-DC converter required to interface sensitive electronic appliances and low-voltage battery storage. However, these issues have been addressed in PCmRC architecture. The remaining paper consists of four sections. In Section II, the overall architecture of DCT enabled consumer grid is presented in detail. The DCT topology is discussed in section III. In Section IV, some advantages of PCmRC architecture are listed down over state-of-art models and conclusion is in Section V.

II. DESCRIPTION OF PCmRC MODEL

In order to mitigate aforementioned problems, PCmRC based DC microgrid architecture has been proposed in this section. The PCmRC is scalable and standard model of future consumer grid, which can be integrated into existing infrastructure without any significant change. It can handle AC/DC loads and energy storage. It also helps in solving grid stability problems and maximizes exploitation of renewable sources within consumer grid. The motivation behind standardized grid model is to reduce the production cost and fault rectification time. The proposed layout of PCmRC consumer grid model is shown in Figure 2. Following are the key features of this architecture.

a) Energy efficient architecture: The PCmRC model is based on DC power, which gives several advantages over conventional AC grid such as i) DC can be store easily at small scale. ii) Due to penetration of DC powered loads such as LED lights, smart-phones, LCD etc. in our societies, it reduces multiple power conversion losses. iii) Mostly renewable sources generate DC power; therefore integration of multiple sources became simple. iv) As compared complex parameters of AC power, the voltage's magnitude is the only control parameter in DC grid. v) In DC grid, high power quality without any harmonics and power factor correction unit. vii) There is no frequency synchronization required at any stage in DC powered grid.

b) System power management and control: The main control and power management of PCmRC is based on DC transformer (DCT), which is the brain of PCmRC model as shown in the Figure 1. DCT is a bi-directional and configurable DC-to-DC converter module, which is responsible to regulate both high-voltage and low-voltage DC buses with embedded protections from any type of fault and continuously managing grid's storage as shown in Figure 2(b). Multiple modules of DCT can be cascaded in series or parallel, in order to fulfil load requirements as shown in Figure 2(a). DCT modules are distributed as per load requirements and autonomously control and manage entire grid.

c) Scalable, standard and modular Architecture: The main advantages of DCT enabled PCmRC-grid model is the standard architecture leads to lower production cost and fault tracing time. Moreover, high level of reliability can be achieved by introducing multiple level of redundancy as shown in Figure 2(a). Therefore, wide range of demand-side power requirements can be fulfilled by cascading multiple modules together and power system can be configured easily as per consumer demand.

d) Standard plug-and-play interface for power sources & storage: In PCmRC grid model, there are two buses consist of high voltage and low voltages, as indicated in Figure 2, all sources including AC-grid and storages are plug-and-play like computer "*USB – port*". The renewable energy sources are inconsistence in nature and usually do not provide uniform power all the time, therefore intelligent PCmRC model always maximizes the utilization of renewable energy sources and takes only balance power from the maingrid.

e) Compatibility with existing infrastructure: As mentioned above, all sources and storage are plug-and-play. If there is no renewable source and storage connected, then PCmRC will start taking power from maingrid. Furthermore, PCmRC can manage power requirements with or without renewable sources, storage devices and grid connection. Therefore, in existing infrastructure where the primary source of power is only AC maingrid, PCmRC can drive entire DC microgrid on AC maingrid perfectly without any additional up-gradation.

f) Dual DC Bus: PCmRC uses two DC buses (i.e.300V to 380V) HV-DC bus and selectable (i.e. 12V to 48V) LV-DC buses. The advantage of selecting HV and LV DC buses are: i) High voltage 300V to 380V DC is used for DC power distribution and as a drive for heavy loads. ii) High voltage DC reduces total harmonic distortion (THD) from 70% to 30%, if we change the voltage from 110V to 300V [28]. iii) The design of power–inverter (DC to AC) became simple with high voltage DC. iv) High voltage DC distribution is 7% more efficient then AC distribution in utility grid [31, 2]. v) AC maingrid and wind generator can be directly coupled on High DC bus. iiv) Low voltage DC is used to drive sensitive electronic load. iiiv) Battery storage can be directly coupled on LV DC bus without any additional boost converter.

g) Shunt-fault protection and voltage sag ride through capability: In PCmRC, DCT module is used for power distribution and managing power within the grid, each DCT is continuously monitoring current and voltages levels of both HV and LV DC buses. Therefore, on detecting any anomalous situation, DCT immediately switched-off and isolates the fault. In PCmRC model, battery storage can be directly coupled without additional converter. Therefore, it has voltage-sag ride through capability and suitable for sensitive electronic loads.

h) Estimation of State-of-charge: In PCmRC, the battery storage directly coupled on the LV and HV DC bus of DCT module through simple switch. Therefore, PCmRC continuously monitors the State-Of-Charge (SOC) and only allow extracting power from storage when battery's SOC is within operational range.

i) Off-Grid and Islanding operations: Off-grid and remote power systems are independent from utility power grid such as remote telecom sites, military bases, check-posts, aircrafts, ships, detainee and training centres. Since, all sources and storage in PCmRC are plug-and-play and PCmRC intelligently manages available power either only from maingrid or solely from renewable sources (if any). Therefore, during maingrid fault (weak-islanding) or in the absence of utility grid, PCmRC manages power only from renewable sources and available storage.

j) Compatibility and power sharing with adjacent grids: PCmRC can manage power from renewable sources and from maingrid. In worst weather conditions and unpredicted power demand, if renewable sources are not generating rated power and storage is also not enough for backup supply. In order to avoid load shedding PCmRC will start taking power from maingrid. Furthermore, PCmRC can manage power requirements with or without renewable sources, storage devices and grid connection as shown in the Figure 2. Therefore, in existing infrastructure where the primary source of power is only AC maingrid, PCmRC can drive entire DC consumer grid on AC maingrid perfectly without any additional component or up-gradation. The proposed PCmRC model will be capable enough to simultaneously handle bi-directional power flow from AC maingrid to DC microgrid and vise versa. In case of off-peak hours, if renewable sources are generating power greater than the load requirements and energy storage is also fully charged, then that surplus energy can be sold back to the maingrid. In this way, revenue can be generated by selling surplus energy generated by renewable sources.

k) Load classification and management Unit: The unique feature of PCmRC grid model is the power distribution scheme depends upon the priority level of the load. Therefore, PCmRC manages the critical and noncritical loads without any extra power management device. Moreover, PCmRC can handle both AC and DC power loads connected to the consumer grid. In PCmRC grid model, the load is classified into two groups based on the consumer requirements i.e. critical and noncritical loads. In worst case scenario, during maingrid fault, limited generation from renewable sources and without sufficient energy storage, PCmRC makes sure continuous power supply for only the critical loads. Therefore, PCmRC allows consumer to configure the priority level of the loads.

l) AC and DC powered loads: As mentioned in the previous sections, there are two DC buses HV and LV used in PCmRC consumer grid. The low voltage DC bus can be used for low-power sensitive DC loads and battery storage. The high voltage DC bus can be used to power-up the high power DC loads as well as AC loads. In [23], author did series of experiments and on the bases of successful results proposed that high DC voltage (>270V DC) can be used directly to power up resistive type of AC loads. Furthermore, only few components required to convert 300V DC into to 220Vrms AC supply for inductive load as indicated in Figure 2(c).

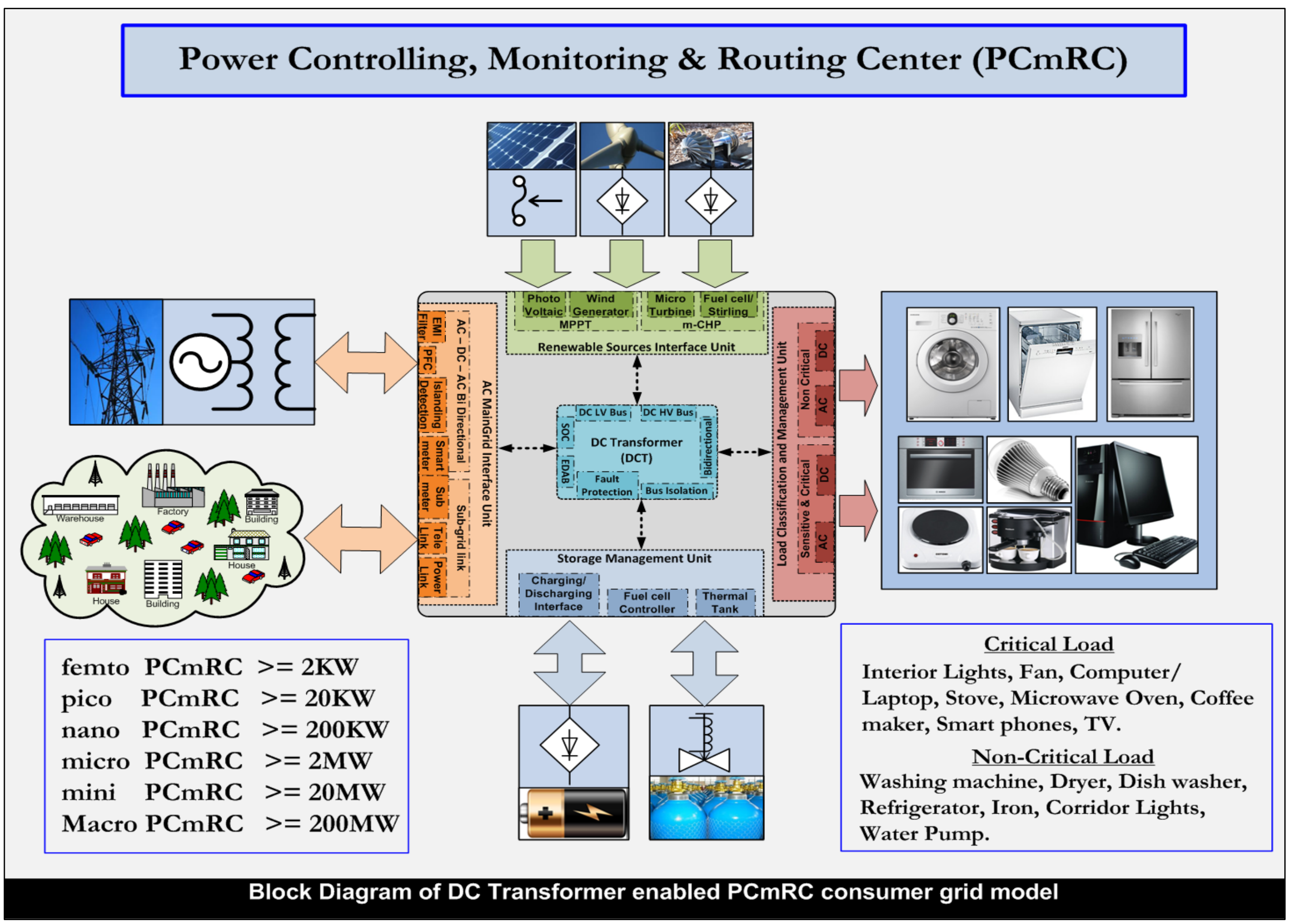

Figure 1: Block Diagram of PCmRC consumer Grid

III. OVERVIEW OF DC TRANSFORMER

DC transformers or power electronics transformers are the modern form of convectional transformers with additional features such as in-system protections, harmonic isolation, small size, reduce weight, small foot-print, fault tolerance etc. Extensive topologies have been proposed for solid-state transformers such as Dual half bridge (DHB) [15], Series resonant Converter (SRC) [9], Cascaded Buck-Boost (CBB), Combine half bridge (CHB) [1], Dual active bridge (DAB) [42], L-Type half bridge [14], IEM [41, 36], ECC [13], IUT [19], Gen-1 SST [37], PSM-ZVS PET [27]. However, all above proposed topologies and models are used for AC-AC and AC-DC bidirectional conversions. Moreover, few of them can be used for DC-DC conversion such as DHB, SRC and DAB, but they do not meet the basic PCmRC power management requirement. DHB provides less reactive power because of single end isolation [9]. In SRC, due to active components the operating range of the converter becomes limited and control becomes complicated. The DAB topology is unsuitable for LVDC applications due to the limited range of voltage regulation.

DC transformer (DCT) based microgrid is a distinct approach proposed to solve power management and control issues. DCT module used in the PCmRC is the DC to DC converter having isolated high voltage and low voltage side and it can manage bi-directional power flow on each side. DCT has configurable output voltage on each side and multiple DCTs can be cascaded in series and parallel in order to fulfil the power requirements. Each individual DCT is responsible of power controlling, monitoring and routing within grid. DCT is the centre of all activities and each DCT connected on common high voltage bus, as shown in the Figure 2. However, the low voltage bus of each DCT is isolated through high frequency transformer. Therefore, in order to achieve fault isolation, loads always connect on isolated side of the DCT.

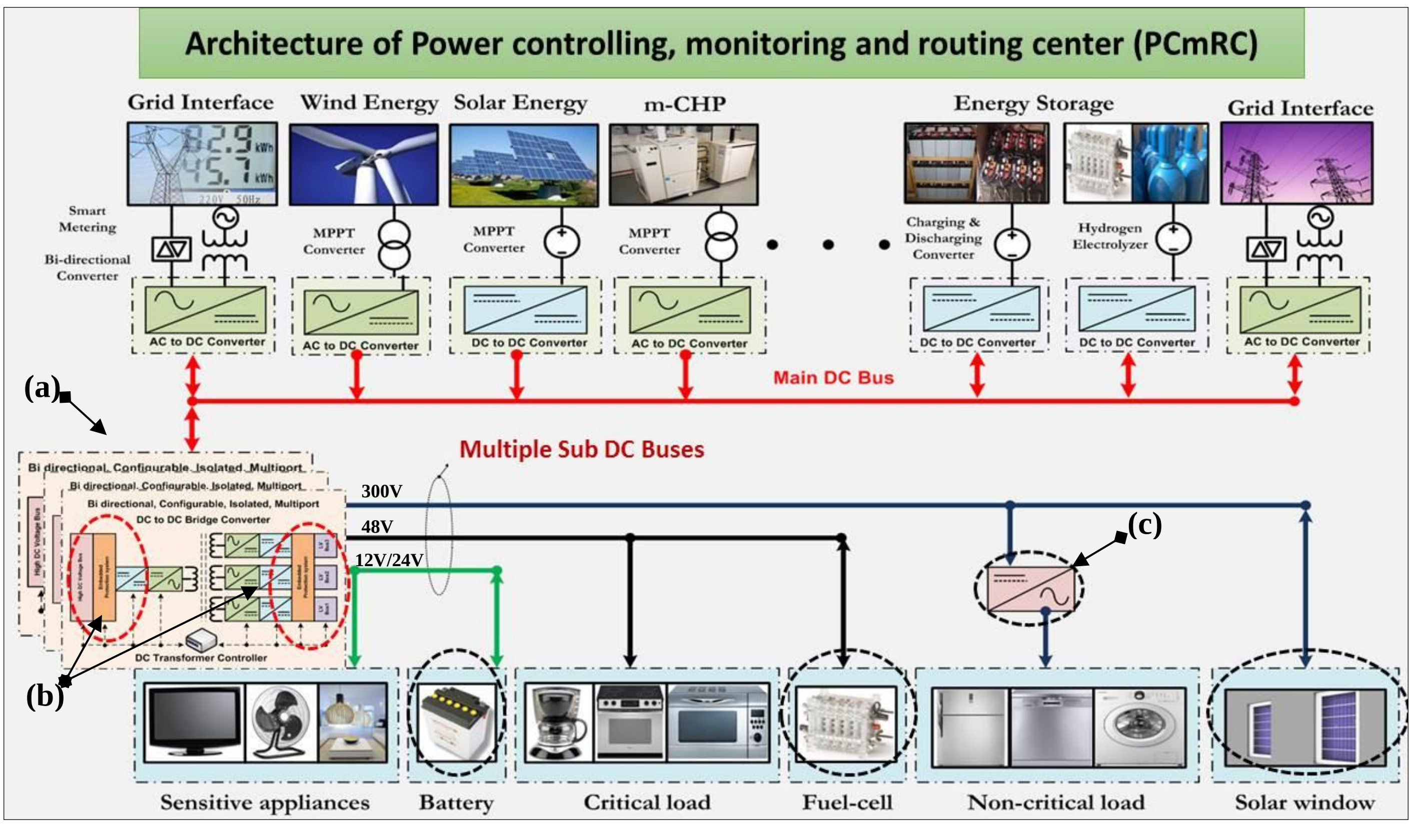

Figure 2: Architecture of PCmRC Grid model (a) Connections of redundant DCT modules (b) Embedded DC Bus protections on each side (c) HV-DC to AC converter for AC appliances

IV. ADVANTAGES OF PCmRC GRID OVER STATE-OF-ART MODELS

PCmRC is DCT enabled design, which has several advantages over state-of-art AC-DC SST based design. The key advantages are summarized as follows:

- In centralized control, there is single point reliability which is the communication link with fast response [3, 11]. However, in autonomous control, individual node must be intelligent and system becomes slow and expensive [40, 11]. The main advantage of the DCT based control is that DCT reduce the processing burden from connected peripherals like centralized control and multiple DCTs can autonomously control the whole grid. This is the reason, PCmRC model have both advantages of centralized and distributed grid control system.

- In PCmRC model all sources and storage are plug-and-play. Therefore, there is no change in control algorithm for grid-tie, islanding and off-grid operations. However, AC-DC SST grid models are designed for grid connected operations.
- Standard and Modular design of DCT enables the redundancy and reliability of the grid as shown in Figure 2(a). Standardization of DCT design leads to reduce the manufacturing cost and production-time.
- In DCT topology high switching frequency is used for reducing the foot-print of transformer with galvanic isolation between low voltage and high voltage side.
- DCT enable DC microgrid has unity power factor, zero harmonics, with voltage-sag ride through capability.
- DCT ensures proper regulated voltages on each side, which reduces the need of additional voltage regulator. However, in AC-DC SST models, multiple DC-DC converters are used at each node to interface the renewable generators, storage and load.
- Same topology of DCT can be used for DC to AC conversion for AC powered appliances and Grid-tie operations.
- DCT's scalable approach enables to configure the power system for variable input and output power demands at any stage.
- In DCT, low voltage is used for powering the sensitive loads, which is not harmful for human beings; therefore DCT based design is efficient, reliable and safe for human-life.

V. CONCLUSION

A unique distributed power management technique is proposed in this paper for DC microgrids. The PCmRC will be the main component in the future consumer grid, which will be responsible for grid-to-grid communication, real-time power metering, load management and integration of multiple renewable sources, energy storage and AC maingrid. Despite, the presented model can support the operation of whole range of consumer distribution system. Nevertheless, DCT enabled PCmRC may first be implement for residential application, which leads toward next generation sustainable empowering system for Smart-homes and Communities.

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